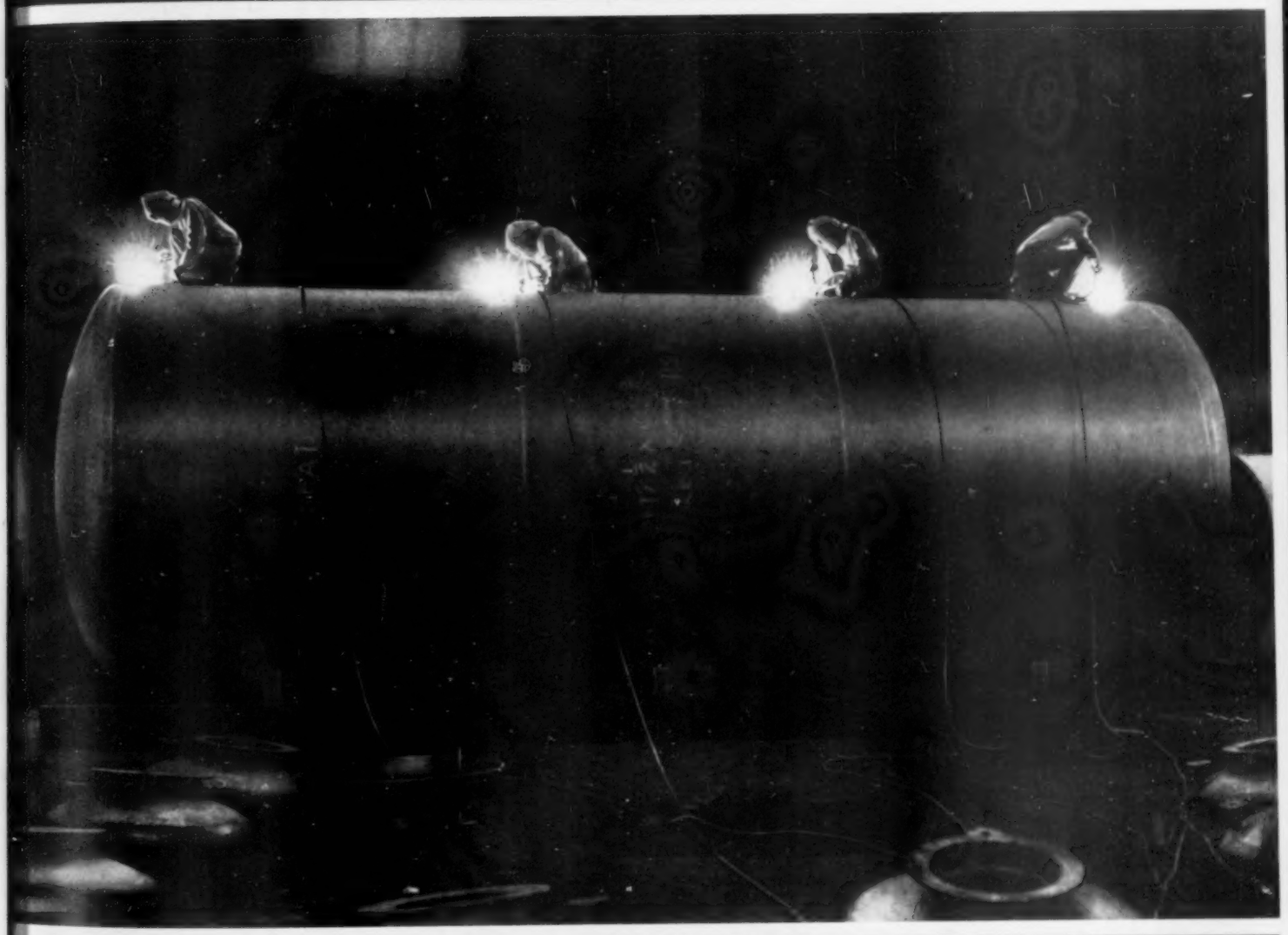
AUGUST 1942

The WELDING Journal



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Metallic Arc Welding of Copper Pressure Vessels

By G. H. Sandberg*

METALLIC arc welding of copper alloy is being applied successfully in the fabrication of pressure vessels to meet code requirements at the Edge Moore Iron Works, Edge Moor, Delaware, where metallic arc-welding techniques have been developed to give more satisfactory results than the carbon arc method for joining copper alloy. An important factor contributing to the X-ray perfect fabrication of these vessels is the elaborate care taken in preparing each piece of the assembly, to insure accurate fit-up.

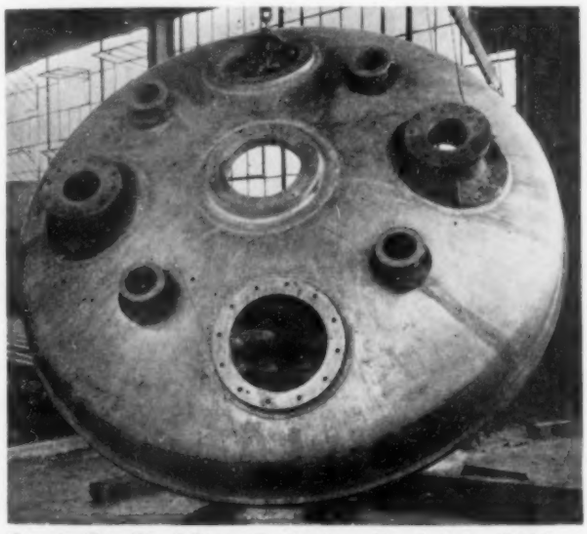

Fig. 1—The Head Piece Is Machine Beveled for Welding Before the Shell Is Formed, to Insure Accurate Fit-Up

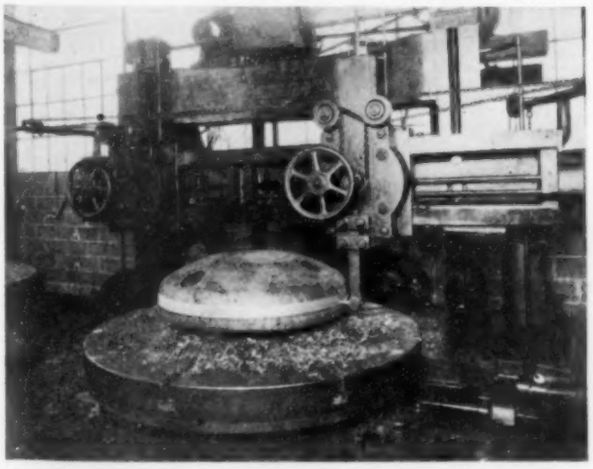

Fig. 2—Boring Mill Setup for Trimming Dished Heads Accurately to Size

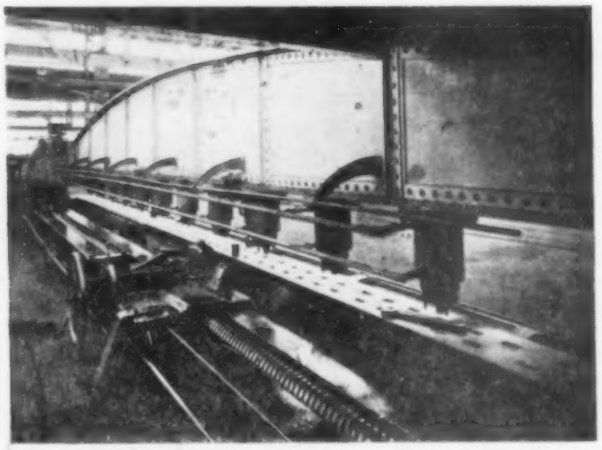

Fig. 3—Precision Fit Ups of Shell Plates Are Accomplished Through the Use of This 30-Ft. Edge Planer, Which Is Equipped with Pneumatic Hold-Downs and Which Planes Both Bevels and Grooves

Typical of the pressure vessels welded in this shop is a $9^1/_2$-ft. diameter tank made of phosphor bronze and entirely welded by the metallic arc process. This is a double-walled vessel, the inner shell being of $^3/_4$-in. bronze, with an outer shell of steel. The construction of this vessel to secure perfect penetration without porosity in the welds, and to avoid uneven stress distribution, was first a problem of accurate machining of all parts.

The subject of fit-up is seldom discussed in the detail it deserves, yet a perfect fit-up is essential to sound construction. The most skilled technique of welding will not compensate for poor preparation, and while it may succeed in producing a smooth contour despite inaccurate alignment, it may do so at the expense of setting up unequal stresses, with consequent loss of strength under pressure. Thus a good fit-up is not accomplished merely by forcing work pieces together in a strong jig. At Edge Moor careful attention is devoted to trimming and shaping of each part, not only to eliminate the danger of offset joints, but because the welding of this alloy demands very skillful arc manipulation, which would be hampered by variations in width and shape of the welding groove.

* Wilson Welder and Metals Company.

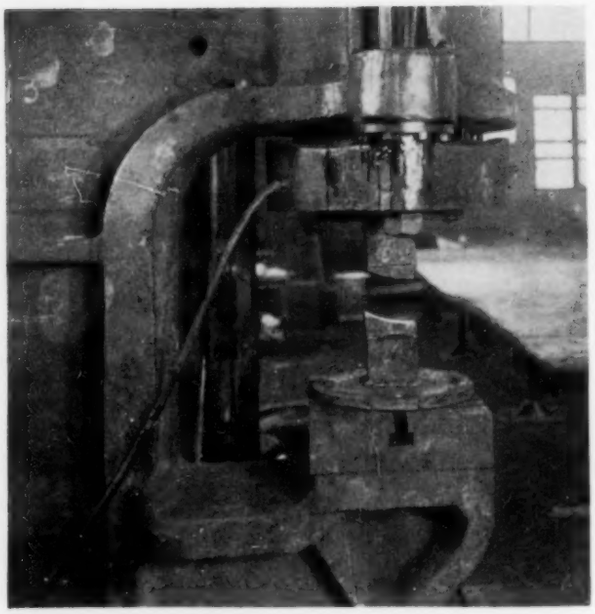

Fig. 4—Crimping Press with Dies for Preliminary Bending of Shell Plate Edges Before Rolling

The shell plates are ordered oversize, with $^1/_4$-in. allowance on each side for machining. These are laid aside until the dished head pieces have been formed and machine beveled on a boring mill. The circumferences of the head pieces are then measured accurately to determine the exact size to which the shell plates must be rolled. This procedure is the first guarantee against offset joints, since it often happens that the heads will differ slightly in diameter, or will be near the limits of specification dimension tolerances. In this way the shell diameter is adjusted for a perfect fit, and may even be tapered slightly since such taper is much less objectionable than a poorly fitted joint.

The shell plate is then laid out and planed for a 35° bevel. Before rolling to shape, a hydraulic crimping press is used to form the metal adjacent to both edges for the longitudinal weld. This shapes the end zones which would be left out-of-round by the cylinder rolls. A slight allowance is made in the forming dies on this press, to leave the finally formed plate a trifle out-of-round so that the contraction of the weld area will draw the cylinder into a perfect cylindrical shape.

The plate sections are then rolled to shape and tack welded along the inside of the longitudinal seam. With the base metal preheated to 200° F. the single V joint is

Fig. 5—Shell Plate Gets Final Forming Operation in These 29-Ft. Long Rolls

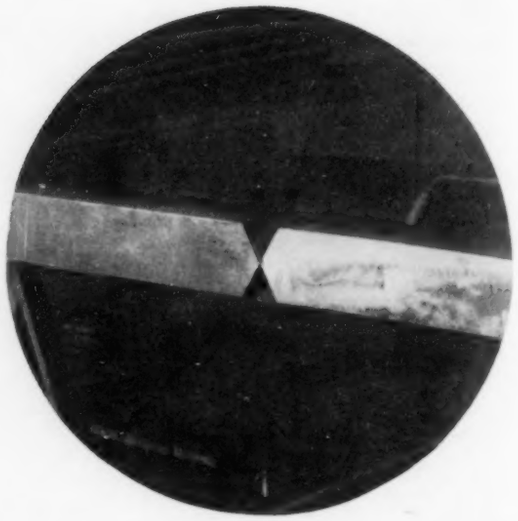

Fig. 6—Three Bars of 3 x 5-In. Copper Are Joined and Rolled to Form a Flange Ring. Metallic Arc-Welded Joints Were Nearly as Strong as the Parent Metal

then filled from the outside. The welding rod used on the pressure parts is a coated rod with low phosphorous content, a type selected after considerable experimentation. The weld root is then chipped out thoroughly and the weld finished on the inside. The shell rings are then fitted against the heads, and if procedure has been correct the perimeters of the abutting edges should be identical in size and shape. Any slight deviations in curvature are corrected on the rolls before tacking on the head piece. The circumferential seams are also of the single V type joint.

Since the design of this tank included several massive flange rings, these were fabricated by joining three lengths of 3 x 5-in. rolled copper bars. The three sections were joined with double V welds which were chipped and ground flush, and the full length bar was then rolled to correct diameter. The closing weld, like the other joints, was made with a bare electrode having high phosphorous content, the base metal having been preheated in this case to approximately 600° F. Destructive tests of these heavy welds showed a tensile strength of 39,000 psi. Maximum tensile strength of the base metal was 45,000 psi.

The elaborate care which goes into the preparation and deposition of these welds is more than justified by the results obtained. X-ray examination revealed that

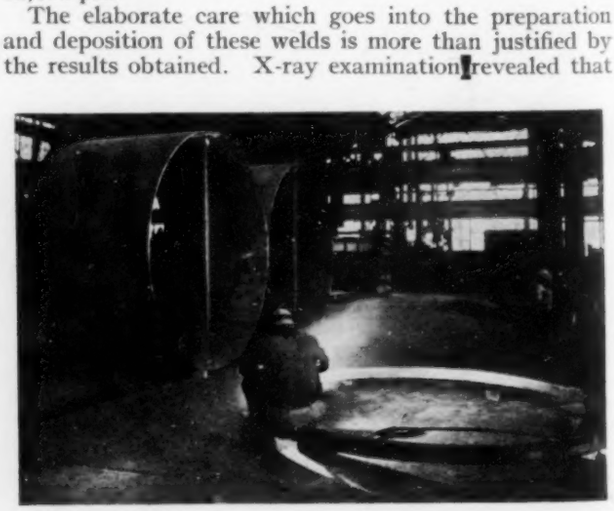

Fig. 7—Operator Is Making the Closing Weld in the Flange Ring. In the Background Are the Bronze Shell and Steel Shell for the Outer Jacket

the joints in the pressure parts were virtually free from any defects whatsoever. Similar joints subjected to destructive tests showed a tensile strength of over 47,000 psi., which was greater than that of the base metal. The highly specialized technique used in the fabrication of these copper alloy vessels is the result of careful experimenting. When the preheat temperature was too high, or when the electrode was deposited at too high a temperature, excessive gas and porosity showed up in the X-ray. Likewise, transverse cracks were sometimes encountered in the joint between shell and flange bar. However, when the correct procedure was established and set up on a production basis, uniformly satisfactory results with 98 to 100% perfect welds were obtained.

The development of these procedures of fit-up and metallic arc welding of copper alloy, as well as stainless steel and other commercial alloys, permits the use of minimum plate thicknesses with complete assurance of adequate strength and uniform stress distribution. For the construction of non-corrosive pressure vessels for the chemical industries, tanks and heat exchangers to meet rigid code requirements, such perfect fabrication is essential.

Stud-Welding System

By A. M. Candy*

General

THE apparatus and devices described herein are based on a method of end-welding studs, screws, bolts or any elongated piece of metal to a metal surface wherein the arc is induced by arc-initiating material which simultaneously furnishes additional bonding metal and acts as a scavenger of oxygen, thus insuring a homogeneous dense fusion weld of the stud or screw to the metal surface. There is also covered herein a method of deck-construction which utilizes this system of end-welding. The method of end-welding, however, is not limited in its application to wood deck-construction, but has numerous applications where an elongated piece of metal is to be end-welded to a metal surface.

The development of the wood deck-construction was initiated by Captain John D. Crecca, U.S.N., at the New York Navy Yard, in collaboration with S. S. Scott, welding engineer, in 1930, and led to the development of the device and method of end-welding, which made it possible to utilize the method of construction. The method of construction and the method of end-welding, as well as the devices therefor, were sufficiently developed, though in a crude form, to make the initial application in the laying of the wood deck planking on 10,000-ton cruiser, U.S.S. *New Orleans*.

The early form of the end-welder utilized power (air) means to project the stud into the arc crater on the instant of striking the arc. This device was cumbersome, lacking mobility and flexibility, which led to the development of a portable hand gun. The portable hand gun found varied application in addition to the use in laying wood decking. The early form of the portable hand gun, while embodying automatic features in projecting the stud into the arc crater on the initiation of the arc, required a preliminary period of training of the welder to insure satisfactory results. To eliminate all "personal element" in the method of end-welding, a fully automatic equipment was developed, which embodied a timing device actuated by the welding current, and an automatic switching device in the gun mechanism so that once the operator has positioned the gun with stud in operating position, his only action is to press a thumb switch in the gun handle. The timing of the duration of the arc, projecting the stud into the crater and disrupting the welding current are all done entirely automatically.

The method of end-welding, as well as the type of deck-construction, has been used on a large number of U. S. naval vessels since 1932, and also on a number of merchant vessels built by the Maritime Commission.

Wood deck planking to be layed by this method must have proper diameter holes located along the plank lengths, said holes being located where studs are required.

Studs welded by this method, when tested, will break through the body of the stud and not in the weld.

The advantages of this machine for end-welding studs, screws, etc., are as follows:

1. Ruggedness and simplicity.
2. Utilizes arc-welding.
3. Combines arc-welding with impact.
4. Wholly automatic, eliminating "personal element" of operator or training of operator.

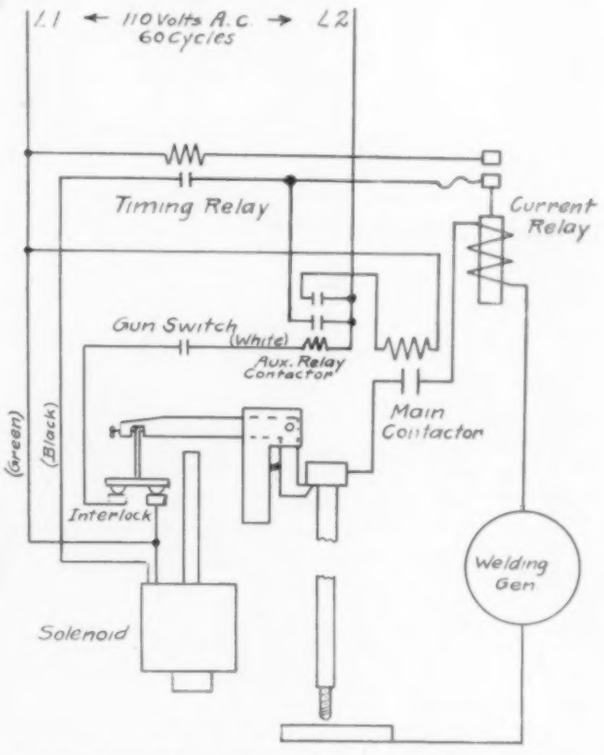

Fig. 1—Shows Scheme of Circuits for Gun and Control Cabinet. Also Shows Circuits to Welding Generator Illustrated by Fig. 6

*Consulting Engineer, Hollup Corporation, Division of National Cylinder Gas Co.

5. The arc-initiating material insures a homogeneous, dense weld free from air holes and sufficient metal to provide a fillet around the base of stud.

Wood Deck-Construction

The procedure in laying deck-planking of this construction is as follows: The planks are counterbored with any spacing of holes. This is the first advantage over the old method employing the bolts of a special type since the studs can be end-welded anywhere on the deck plating without fear of interferences by obstructions, such as wiring, ventilation ducts, etc., underneath. The planks are then laid down in the usual manner, the strakes of planking being laid completely across the deck, if desired. A shipfitter or shipwright goes ahead of the welder with a drill with which he scratches the deck sufficiently to remove paint or oil to insure clear metallic contact. The welding operations are then performed as described above. The shipwright follows the welder and places the grommet, washer and special retaining nut on the stud. A forked T-wrench is used to set up a special nut on the stud. A wood plug, previously dipped in white lead, is pressed into the upper portion of the hole.

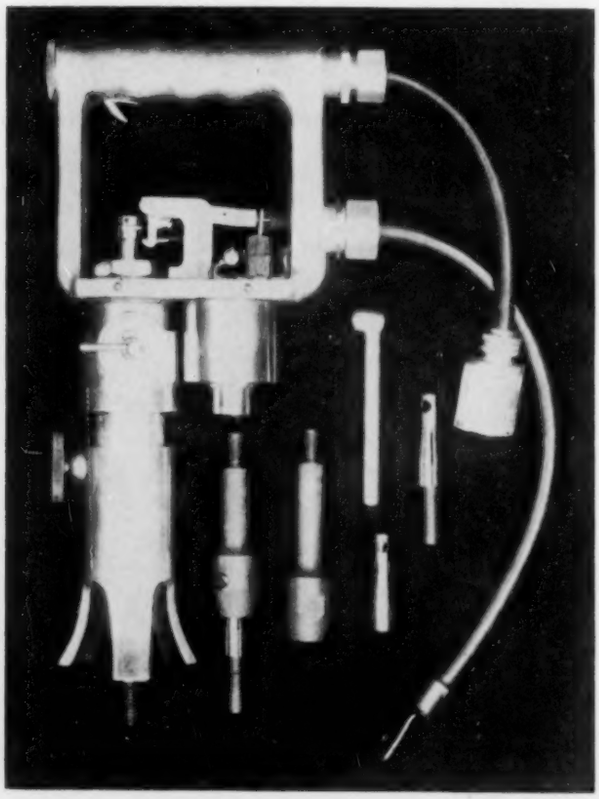

Fig. 2—Shows Gun with Cover Over Mechanism Removed. Also Two Extra Adapters, One with Collet and Stud Inserted. A Spare Collet and One with Stud Inserted. Also an Arc Initiating Material Measuring Spoon. Gun Is Cocked Ready for Setting Arc Gap

Production of end-welded studs with this gun is as high as 1200 per 8-hour day for $^{7}/_{16}$-in. studs. The length of studs used is obviously related to the thickness of deck planking used.

The distinct advantages of this method of laying wood decking and this type of construction are the following:

1. It permits the drilling of a smaller hole in the wood for a given size stud than any other method utilizing arc welding, therefore, retaining greater strength of the planking. The stud fits snug in the lower hole of the wood without the necessity for any excess space between the stud and the wood to protect the wood from the heat of the arc in view of the use of the insulating ferrule or bushing.

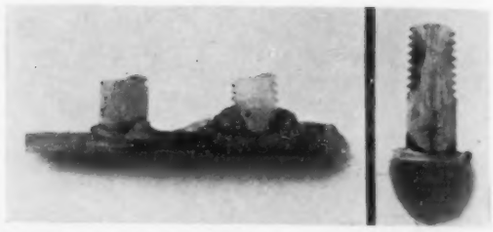

Fig. 3*(Left)*—Polished and Etched Sections Through $^{7}/_{16}$-Inch Diameter Studs Welded to Plates. Left-hand Stud Was Welded Horizontally with Plate Vertical. Righ-Hand Stud Was Welded Downhand

Fig. 4*(Right)*—Polished and Etched Section Through $^{7}/_{16}$-Inch Diameter Stud Welded to $^{3}/_{32}$-Inch Bar $^{5}/_{8}$-Inch Wide. Timing About $^{1}/_{4}$ Second and Current About 600 Amperes Direct Current

2. The insulating ferrule not only saves the wood from the intense heat of the arc, but, also due to an inward flange at the top,prevents spattering of droplets of molten metal from covering the threads of the stud.

3. The shoulder in the counterbored hole can be made wide enough to give good bearing with shearing strength of the wood commensurate with the strength of the stud.

4. It eliminates the costly operation of drilling holes through the metal deck plating and structure underneath. This is a tremendous saving over the through-bolt method.

5. Permits laying wood decking any time after the steel deck is laid, since there is no necessity to wait for run of wiring, ventilation ducts, interior structure, fittings and other attachments under the deck, thus expediting construction.

6. Insures complete watertightness of the deck plating.

7. The form of special nut permits a deeper wood plug in the upper hole and, therefore, more replanings of the deck planking can be done before the deck planking is reduced below a usable thickness. This results in a large saving in the life of the vessel.

8. The stud is simpler and more economical than the special form of carriage bolt used in the through construction.

The foregoing advantages are attested by the number of applications of this method with excellent results.

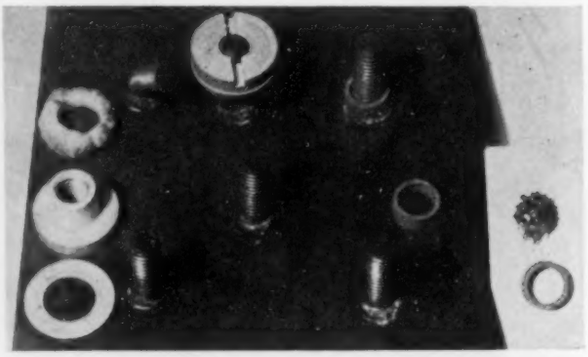

Fig. 5—Shows Two Views of Special Nuts, Also Metal Washer and Cotton Grommet. Hemp Is Also Used for Grommets. Also Lava Rock Ferrules Are Shown Together with a Correct Amount of Arc Inducing Material

Fig. 6—General View of Operator with Complete Stud Welding Equipment

Apparatus

The welding gun is supplied with three adapters of different lengths, three collets and one arc-inducing material dispensing spoon. The gun control circuits are completely wired with leads brought out in a three-conductor rubber-covered cable, through a cable grip to a three-pole connector plug. The gun is also equipped with a terminal for connection to a source of welding current.

The control cabinet panel mounts a main contactor operated by the auxiliary contactor, and one current relay and one timing relay. See Fig. 1.

The gun mounts a solenoid, a latch mechanism and an interlock switch operated by the tail piece of the latch arm.

The electrical circuits of the system are shown schematically by Fig. 1.

Operation

Briefly the operations are as follows. A stud is inserted in the collet. The stud is located in a plank hole with the tripod feet placed firmly on the plank. By means of the two knurled knobs and the small lever in shaft through the upper knob (see Fig. 2) the end of the stud is easily set for the correct arc gap between it and the deck plating. This adjustment need not be disturbed for subsequent studs of same length providing the planking is of uniform thickness and is uniformly in contact with the deck plating. The gun is then removed and a lava ferrule is properly placed in the bottom of the plank hole. A metered amount of arc-inducing material is located in the bottom of the ferrule.

The gun is then placed in position with tripod on the flooring and the stud located in the hole with the stud end touching the arc-inducing material. The trigger switch on under side of gun handle is then depressed. This closes the main contactor, thereby establishing the welding circuit so that welding current flows through the current relay and through the stud and arc-inducing material. The latter immediately flashes and produces an arc. After a certain preset time interval (about $^1/_3$ second) the timing relay (energized by the current relay contacts) closes its contacts which energize the solenoid under the gun handle. The solenoid plunger stem strikes the tail piece of the latch mechanism which releases the internal spring actuated shaft thus impelling

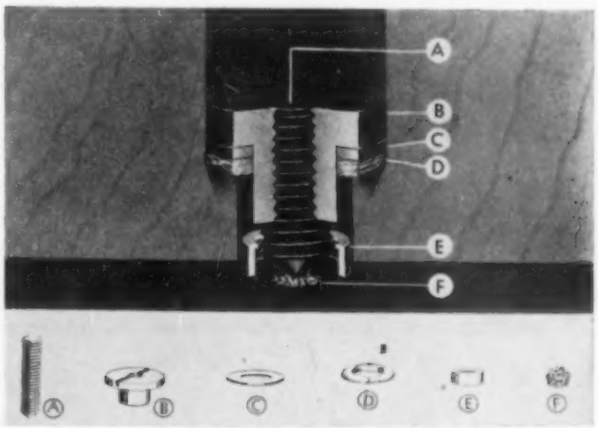

Fig. 11—Shows Assembly of Units Including Wood Plug in Upper End of Hole in Plank

Stud A Is Shown in Contact with Arc Inducing Material F, and Not Welded to Plate. Plug Material Is Same Wood as Used for Wood Decking and Has Its Axis Across the Wood Grain So That It Will Wear at Same Rate as Wood Planking and Will Not Interfere with Subsequent Replainings.

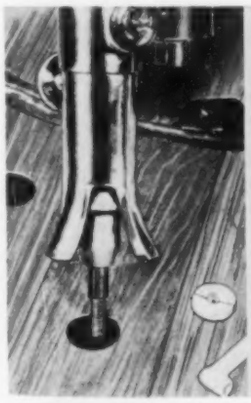

Fig. 7—View of Stud Entering Hole in Planking

Fig. 8—Operator Dropping Lava Rock Ferrule in Hole in Planking Prior to Pouring in the Charge of Arc Initiating Material

Fig. 9—Operator Pouring a Metered Amount of Arc Initiating Material Down Into the Lava Rock Ferrule Located in Bottom of Hole in Wood Decking

Fig. 10—Operator Dropping Assembly of Special Nut, Grommet and Washer Down Over End of Stud Prior to Setting Nut with Special Spanner Wrench

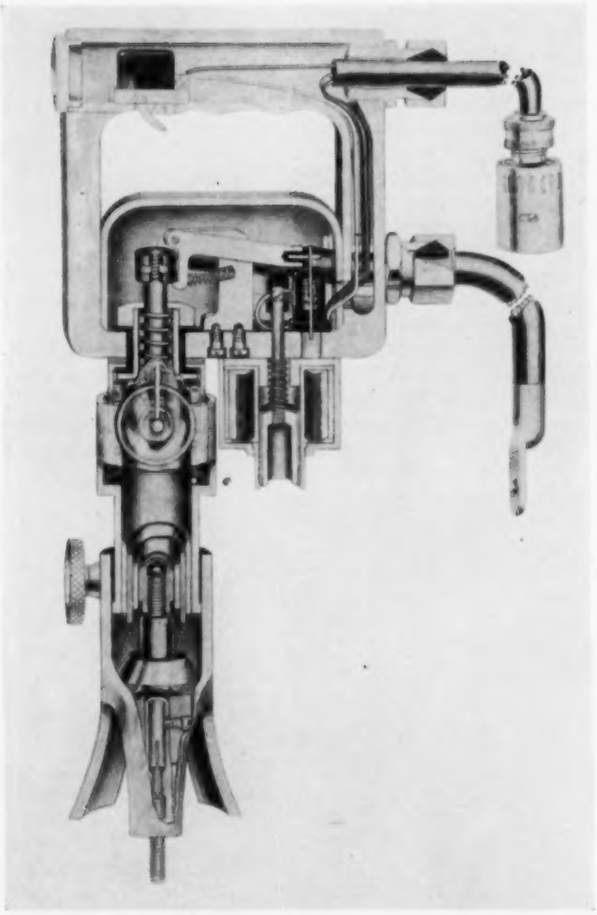

Fig. 12—Cut-Away Views of Gun Mechanism and Parts

the stud end into the pool of molten metal. The tail piece of the latch mechanism also opens the interlock switch located under its end. This switch in turn opens the main contactor which interrupts the welding current automatically.

The various automatic features of this system provide a number of advantages over the former manually controlled welding guns.

First, accidental or false arcing of the gun is prevented because when a stud is inserted in the collet no welding current can be obtained through the stud unless sufficient pressure is put on it to force the central shaft upward against a spring until the latch hook locks under the bottom circular nut at top of shaft, thereby permitting the tail piece of the latch arm to close the interlock switch.

Second, false operation of the gun is also prevented because if the welding circuit is not actually established from the end of the stud through the arc-inducing material and the deck plating no welding current will flow when the main contactor closes and therefore the current relay will not operate. This in turn prevents the timing relay from operating and therefore the gun solenoid will not operate to trip the latch arm. This feature is not provided in other systems.

Third, after the gun has fired under normal conditions, it is impossible for an arc to be formed between the top end of the stud and the end of the collet when the operator pulls the collet off the stud. This is because the welding circuit is automatically opened by the gun interlock switch and is not dependent upon the operator allowing the gun trigger switch to open. Likewise this feature is not provided in other systems.

Quality of Welds

The quality of the welds made with this system is illustrated by Figs. 3, 4 and 5. Figure 4 is a polished and etched section through a $^{7}/_{16}$-in. diameter stud welded to a steel strip $^{3}/_{32}$ in. thick by $^{5}/_{8}$ in. wide. The weld fillet was trimmed off with a special tool. Close inspection reveals that a sizable portion of the stud end is welded directly to the strip. Figure 3 shows polished and etched sections of same size studs welded to heavier plates. The left-hand stud was welded to the plate in the vertical position which results in a minimum of fillet material surrounding the junction. The right-hand stud was welded down-hand. Each of these views also shows an appreciable portion of the stud center, welded directly to the plate.

Studs welded with this system extend a very uniform distance above the deck plating, with uniform fillets around their ends as illustrated by Fig. 5. When these studs are tested to destruction, failure always takes place through the stud and not in the weld.

In carrying out this welding work a direct current generator is used to supply the welding power. For all general purposes the best results are obtained with the timing and current values given by Table 1.

Table 1

Stud Diameter	Welding Current, Amp.	Time in Second	Setting Indicated on Timer Dial Is Cycles Based on 60 Cycles per Second
$^{1}/_{8}$	250	$^{1}/_{6}$	10
$^{1}/_{4}$	475	$^{1}/_{4}$	15
$^{5}/_{16}$	550	$^{1}/_{4}$	15
$^{3}/_{8}$	625	$^{1}/_{4}$	15
$^{7}/_{16}$	775	$^{1}/_{3}$	20
$^{1}/_{2}$	1000	$^{25}/_{60}$	25

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AMERICAN WELDING SOCIETY, 33 West 39th Street, New York, N. Y.

Proposed Specifications for Stainless Steel Arc-Welding Electrodes for Welding Steels of High Hardenability*

IMPORTANT NOTICE: These proposed Specifications have not been approved by the SOCIETY, but are being published for the purpose of eliciting comments, suggestions and criticisms. Criticisms of the Specifications should be submitted to M. M. Kelly, Secretary, AMERICAN WELDING SOCIETY, 33 West 39th St., New York, N. Y., and must be received not later than October 15, 1942, in order to receive consideration.

Scope

1. (*a*) These specifications cover heavily covered metal arc-welding electrodes of the stainless (chromium-nickel) type for manual welding of hardenable low alloy steels.

NOTE: *In connection with welding steels of high hardenability, the requirements of these specifications pertain to tensile strength and elongation of the deposited metal and not to high- or low-temperature characteristics, creep properties, heat or corrosion resistance. The purpose of these specifications is to assure uniformity of the quality of the weld metal for those electrodes which have been previously approved by the purchasing agency for the welding of steels of high hardenability.*

(*b*) The electrodes are classified on the basis of ultimate tensile strength, elongation and analysis of all-weld-metal specimens in the as-welded condition, as shown in Table 1.

Manufacture

2. The electrodes may be made by any methods that will yield a product conforming to the requirements of these specifications.

Standard Sizes and Lengths

3. Standard sizes and lengths of electrodes are as shown in the following table. In all cases, standard size refers to the diameter of the core wire.

Standard Sizes, Diameter of Core Wire, In.	Standard Lengths, In.
1/16, 5/64, and 3/32	9 or 18*
1/8, 5/32, 3/16, and 1/4	14
5/16	18

* In the case of 18-in. lengths of 1/16, 5/64 and 3/32-in. electrodes, center gripping of the electrodes is standard. In all other cases, end gripping is standard.

Chemical Composition

4. The electrodes shall be capable of depositing metal conforming to the requirements as to chemical composition prescribed in Table 1.

* Prepared by AMERICAN WELDING SOCIETY Filler Metal Specifications Committee.

Table 1—Chemical and Tensile Requirements of Deposited Metal

	Class Designation		
	18-8 Mn	18-8 Mo	25-20
Carbon, %	0.20 max.	0.20 max.	0.20 max.
Manganese, %	2.0 to 5.0	3.0 max.	3.0 max.
Chromium, %	18.0 min.	18.0 min.	24.0 min.
Nickel, %	8.0 min.	8.0 min.	19.0 min.
Molybdenum, %	1.25 max.	1.0 to 4.0	..
Tensile strength, min., psi.	80,000	80,000	80,000
Elongation in 2 in., min., %	35	35	35

Chemical Analysis

5. The sample for analysis shall be prepared as follows: A 1 1/2 by 1 1/2 by 1/2-in. pad of superimposed layers of weld metal shall be prepared on a piece of standard base metal (see Section 12 (*a*)). The top surface shall be cleaned by grinding or machining and a one- to two-ounce sample obtained from the top layers in such a manner that the maximum penetration of the cutting tool into the pad is not closer than 1/4 in. to the base metal.

Tension Tests

6. Tension tests shall be made as prescribed in the following Paragraphs (*a*) to (*e*).

(*a*) The steels to be used for test plates shall conform to either of the following specifications of the American Society for Testing Materials:

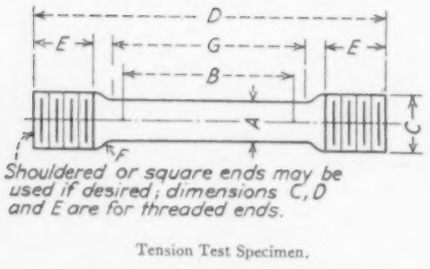
(1) Standard Specifications for Carbon-Steel Plates for Stationary Boilers and Other Pressure Vessels (A.S.T.M. Designation: A 70).

(2) Standard Specifications for Steel for Bridges and Buildings (A.S.T.M. Designation: A 7), open-hearth or electric-furnace steel.

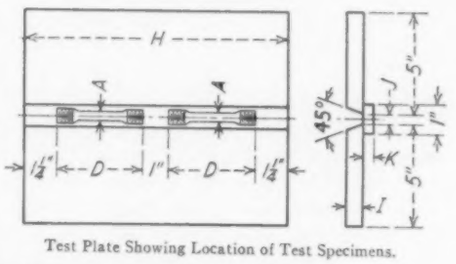
(*b*) For electrodes smaller than 1/8 in., the all-weld-metal tension test is not practical and the strength of these sizes shall be judged by the strength of 1/8 in. or larger electrodes of the same class designation.

(*c*) For electrodes 1/8 in. and larger a test plate shall be prepared as shown in Fig. 1. The plate shall be insulated from the welding bench by 1/2 in. of asbestos during welding. After the joint has been tacked, the assembly shall be heated in boiling water for 5 min. prior to welding. After depositing each pass, the assembly shall be left on the asbestos to cool in still air for 10 min., and then immersed in boiling water for 5 min. Each subsequent pass shall be deposited immediately after removal from boiling water. After the last pass, the assembly shall be removed from boiling water after the 5-min. period. If it is necessary to interrupt the pass sequence prescribed above, the assembly shall be removed from boiling water after a 5-min. period and allowed to cool in

Electrode Size, In.	Test Plate Thickness, In. I	Number of Layers	Diameter of Tension Test Specimen, In.	Dimensions of Test Plate and Tension Test Specimen, In.								
			A	B	C	D	E	F	G	H	J	K
1/8	1/2	8 to 9	0.252 ± 0.005	1	3/8	2 1/2	1/2	3/16	1 1/4	8 1/2	1/4	3/16
5/32	3/4	10 to 11	0.500 ± 0.01	2	3/4	4 1/4	3/4	3/8	2 1/4	12	1/2	1/4
3/16	3/4	9 to 10	0.500 ± 0.01	2	3/4	4 1/4	3/4	3/8	2 1/4	12	1/2	1/4
1/4	1	12 to 13	0.500 ± 0.01	2	3/4	4 1/4	3/4	3/8	2 1/4	12	1/2	1/2
5/16	1 1/4	10 to 11	0.500 ± 0.01	2	3/4	4 1/4	3/4	3/8	2 1/4	12	1/2	1/2



Tension Test Specimen.



Test Plate Showing Location of Test Specimens.

Fig. 1—Requirements for Preparation of Tension Test Specimens

still air at room temperature. When ready to resume work, the assembly shall be preheated in boiling water for a period of 5 min. The work shall be done at room temperature of not less than 60° F. and in the flat position. Weaving shall be the full width of the groove up to three times the diameter of the core wire, when the layer shall be divided into two passes overlapping. Test plates shall preferably be so supported that warping due to welding will not cause the finished test plate to be out of line by more than 5°. If test plates become warped more than 5° they shall be straightened cold.

(*d*) Two all-weld-metal tension test specimens shall be machined from the finished test plate as shown in Fig. 1, and shall conform to the requirements as to tensile strength and elongation prescribed in Table 1.

(*e*) If either specimen fails, another test plate shall be welded and both specimens shall conform to the requirements as to tensile strength and elongation prescribed in Table 1.

Permissible Variations in Dimensions

7. (*a*) Electrodes shall be bare or free from covering for a distance of about 1 in., but not more than 1 1/4 in., for making contact with the holder.

(*b*) The arc end of each electrode shall be sufficiently bare to permit easy striking of the arc, but the length of the bare portion of the arc end, measured from the end to the point where the full cross section of the coating obtains, shall not exceed one core wire diameter or in any case be more than 1/8 in.

(*c*) The diameter of the core wire shall not vary more than plus or minus 0.003 in. from the standard size specified. The length shall not vary more than plus or minus 1/8 in. from that specified.

(*d*) The covering on electrodes of all sizes shall be concentric to the extent that the maximum core-plus-one-covering dimension shall not exceed the minimum core-plus-one-covering dimension by more than 5%. The concentricity shall be measured by any suitable means, such as the following:

The covering shall be removed from one side of the electrode (care being taken to insure that no metal is removed from the core) at about the middle of its length. The core-plus-one-covering dimension (which is the diameter of the core plus the thickness of the covering on one side) shall be measured with a micrometer. The covering shall be removed from the opposite side of the electrode at a point distant from the place where the covering was previously removed, and a similar measurement made. Two more pairs of measurements of the core-plus-one-covering dimension shall be made on planes at angles of 60 and 120° from the plane of the former measurements. The pair of measurements which shows the greatest percentage of variation shall be used in determining the acceptability of the electrode.

Electrode Coverings

8. (*a*) The coverings shall, when cool, have sufficient electrical resistance to effectively insulate against a difference of potential of 100 v.

(*b*) The slag produced shall be readily removable.

Workmanship

9. The coverings shall be such that they are not readily damaged by ordinary handling and shall be of commercially uniform thickness and shall present a workmanlike appearance. Coverings shall be free from injurious scabs, blisters, abnormal pockmarks, bruises or other surface defects.

Packing

10. Electrodes shall be suitably packed, wrapped, boxed or crated to insure against injury during shipment or storage. Standard packages are 50 lb. net weight.

Marking

11. All packages shall be legibly marked with the following information:

(*a*) Class designation.
(*b*) Manufacturer's name and trade designation.
(*c*) Standard size and length.
(*d*) Guarantee.

Guarantee

12. The manufacturer shall make tests at frequent intervals in accordance with the methods prescribed in these specifications, and shall guarantee that the electrodes in all sizes and classes conform to these specifications and each container shall be so marked. The manufacturer's responsibility shall be limited to replacement of any electrodes which do not conform to the requirements of these specifications.

Tentative Standards and Recommended Practices and Procedures for Spot Welding of Aluminum Alloys*

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Personnel of
Aircraft Resistance Welding Standards Committee

G. S. Mikhalapov, *Chairman*

850 Euclid Avenue, Cleveland, Ohio

Eastern Division

P. H. Merriman, *Chairman*, The Glenn L. Martin Company, Baltimore, Md.
Peter Altman, Manufacturing Research Division, Vultee Aircraft, Inc., 7 Avalon St., Detroit, Mich.
R. E. Anthony, Goodyear Aircraft Corporation, Akron, Ohio
L. W. Boelter, Airframe Welding Division, Ford Motor Company, Willow Run Plant, Ypsilanti, Mich.
Robert E. Bowman, 2nd Lt., Air Corps, Army Air Forces, Wright Field, Dayton, Ohio
R. L. Briggs, Thomson-Gibb Electric Welding Co., Lynn, Mass.
Howard C. Cogan, National Electric Welding Machine Co., Bay City, Mich.
E. Courtemanche, Briggs Mfg. Company, Detroit, Mich.
J. W. Dawson, Raytheon Mfg. Company, 190 Willow St., Waltham, Mass.
Fred Flader, Curtiss Airplane Division, Curtiss-Wright Corporation, Buffalo, N. Y.
Alternate: Bernard Gaines
E. H. Foss, Murray Body Corporation, Detroit, Mich.
G. W. Garman, General Electric Company, Schenectady, N. Y.
J. T. Gray, Technical Department, Aeronautical Chamber of Commerce of America, Inc., Shoreham Building, Washington, D. C.
F. R. Hensel, P. R. Mallory & Company, Inc., Indianapolis, Ind.
G. O. Hoglund, Aluminum Company of America, New Kensington, Pa.
Alternate: G. S. Bernard, Jr.
S. M. Humphrey, Taylor-Winfield Corporation, Warren, Ohio
H. J. Kligora, Republic Aviation Corporation, Farmingdale, N. Y.
T. R. Lawson, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.
Colonel D. L. Lingle, Working Committee of Army and Navy, Aeronautical Board, Washington, D. C.
R. R. Moore, Naval Aircraft Factory, Navy Yard, Philadelphia, Pa.
F. H. Morris, Fleetwings, Inc., Bristol, Pa.
Jack Ogden, Central Engineering Division, Fisher Body Corporation, Detroit, Mich.
W. F. Partridge, Grumman Aircraft Engineering Corp., Bethpage, Long Island, N. Y.
N. E. Promisel, Bureau of Aeronautics, Navy Department, Washington, D. C.
S. L. Rich, Bell Aircraft Corporation, Buffalo, N. Y.
R. G. Robinson, Coordination Office, National Advisory Committee for Aeronautics, Washington, D. C.
H. W. Schmidt, Dow Chemical Company, Midlands, Mich.
Mario Sciaky, Sciaky Brothers Corporation, 11001 Cottage Grove Ave., Chicago, Ill.
G. N. Sieger, S-M-S Corporation, 1165 Harper Ave., Detroit, Mich.
C. C. Titherington, Brewster Aeronautical Corporation, Long Island City, N. Y.
A. A. Vollmecke, Engineering Division, Department of Commerce, Civil Aeronautics Administration, Washington, D. C.
T. A. Wilson, Vought-Sikorsky Aircraft Division, United Aircraft Corporation, Bridgeport, Conn.
B. L. Wise, Federal Machine & Welder Company, Warren, Ohio.

Western Division

H. L. Chiles, *Chairman*, Lockheed Aircraft Corporation, Burbank, Calif.
B. Binge, Hughes Aircraft Company, Santa Monica, Calif.
Frank B. Bolte, Boeing Aircraft Company, Seattle, Wash.
E. Dean, Vultee Aircraft, Inc., Downey, Calif.
Alternate: A. L. Barnard, Engineering Development Division
L. E. Earnest, Solar Aircraft Company, San Diego, Calif.
B. Gross, Rohr Aircraft Company, Chula Vista, Calif.
G. M. Guy, Douglas Aircraft Company, Santa Monica, Calif.
C. L. Hibert, Consolidated Aircraft Corporation, San Diego, Calif.
Maurice Nelles, Lockheed Aircraft Corporation, Burbank, Calif.
J. G. Oberholtzer, North American Aviation, Inc., Inglewood, Calif.
T. E. Piper, Northrop Aircraft, Inc., Hawthorne, Calif.
E. R. Siefkin, Vega Aircraft Corporation, Burbank, Calif.

Introduction

THESE Tentative Standards and Recommended Practices and Procedures have been prepared in an attempt to assist fabricators of aircraft and aircraft parts in adapting and using the spot welding process. Since the art of spot welding, when applied to aluminum alloys, is comparatively new and is still in a highly fluid condition, with improvements and new developments occurring rapidly, these Standards and Recommended Practices and Procedures are not intended as permanent but rather as a temporary guide reflecting primarily the conditions existing at the time of their issue. It is the hope of the Committee that they will serve as an incentive for the industry to develop methods and procedures which would represent improvements of the practices recommended herein and will permit raising of standards of quality and performance in the near future.

It is the intention of the Committee to keep in close touch with the industry and incorporate any improvement or development of the art in these Standards and Recommended Practices and Procedures by frequent and periodic revisions. Accordingly, the fabricators of aircraft and its parts, and in general all users of aluminum spot welding process, are urged to communicate to the Committee all improvements in the process which they may develop as well as all suggested revisions and changes they may find desirable in order that the entire industry may share the benefits of individual accomplishment at the earliest possible time.

The communications may be directed to the members of the Committee or may be sent direct to the Committee's headquarters at 850 Euclid Avenue, Cleveland, Ohio.

It is specifically understood that these Standards and Recommended Practices and Procedures apply only to the spot welding form of the Resistance Welding process as defined by American Welding Society and that whenever the word welding occurs it is understood to refer to this form of the welding process only. It is further understood that except when stated to the contrary, they are applicable to all forms of spot welding irrespective of the means, methods or equipment used.

EDITOR'S NOTE—*These Standards and Recommended Procedures are available in Pamphlet Form together with a series of Tables on Electrode Performance Data, Machine Settings Data and Welding Schedules—Price $1.00*

Tentative Standards and Recommended Practices and Procedures for Spot Welding of Aluminum Alloys

Foreword

These Standards and Recommended Practices and Procedures are based on the state of the welding art and technique existing in U. S. A. at the beginning of 1942, as portrayed by the data submitted to the committee. As both the welding art and its use in industry are developing at a very fast rate, it is to be expected that revisions of and additions to these Standards will be required almost continually and it is the intention of the Committee responsible for these Standards to provide such revisions and additions at frequent intervals.

For the same reason and because the application of spot welding process to aluminum and its alloys is comparatively new, it is at present impractical to prescribe a definite standard of practice or requirement for a number of more controversial phases of the process. Consequently in such cases a recommendation only is made, with the intent that though in the majority of cases the recommendation represents the optimum practice or requirement, legitimate exceptions may exist which should not be regarded as incompatible with the proper welding quality and production efficiency.

However, in a majority of cases, sufficient general agreement and sound knowledge exist to permit establishment of a definite standard.

Section I—Standards of Weld Quality

1. *General*

The primary function of a spot or a roller weld is to attach one part to another and to maintain this attachment against the application of design loads to the parts.

In the majority of cases, the loads acting on a spot weld are of two kinds, one with the lines of stress running parallel to the plane of the weld, usually caused by longitudinal shear at the plane of the joint, and the other with the lines of stress running at right angles to the plane of the weld. (See Figs. 1 and 2.)

The large majority of structures are designed so that the load applied to the spot weld is preponderantly of the first or shear type with only a slight component of the second or tension type.

In most materials, the ability of a weld to resist the tension type of stress is a direct function of its ability to resist the first or the shear type of stress. However, the relationship between the two varies greatly depending on the material and to some extent on welding technique.

At this time the exact relationship between the resistance of aluminum spot welds to the two types of stress has not been clearly established though sufficient indication exists that the ratio of the two strengths is adequate for most practical purposes in spot welds generally considered satisfactory in all other respects.

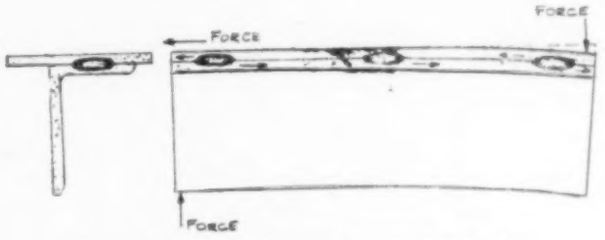


Fig. 1—Longitudinal Shear Stress in Spot Welds

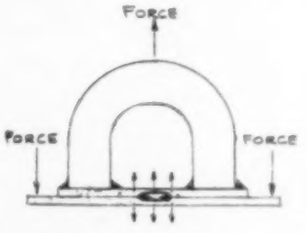
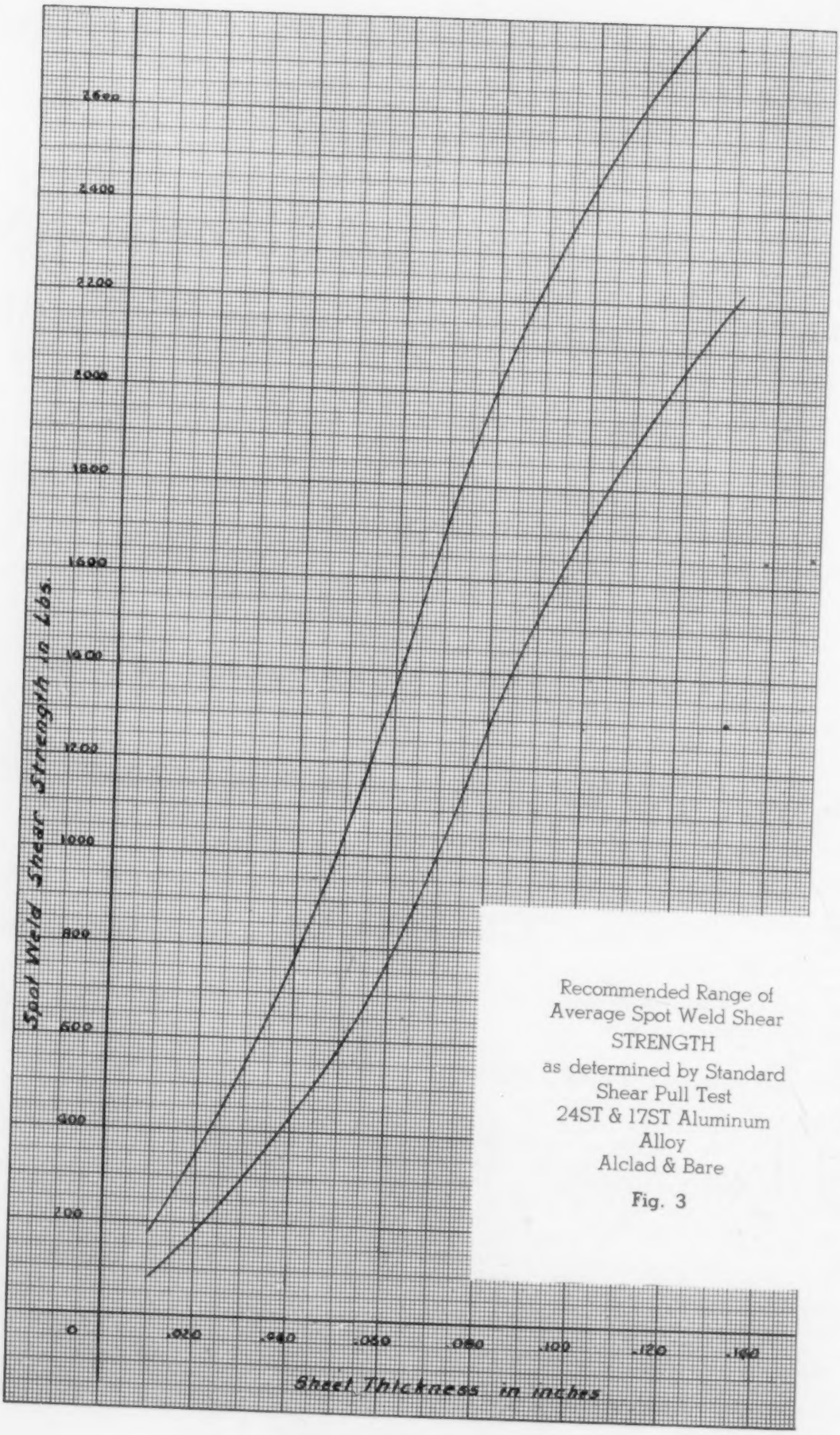


Fig. 2—Direct Tension Stress in Spot Welds

For these reasons these Standards of weld quality are based primarily on the ability of the spot weld to resist the shear type stress or on its shear strength as evidenced by standard shear pull test.

Similarly, insufficient data on fatigue performance of spot welds now available preclude intelligent consideration of this property of spot welds in their evaluation and accordingly these Standards are based primarily on the static properties of spot welds.



Recommended Range of
Average Spot Weld Shear
STRENGTH
as determined by Standard
Shear Pull Test
24ST & 17ST Aluminum
Alloy
Alclad & Bare

Fig. 3

In addition to the basic shear strength requirement, a good weld must also possess certain other qualities if its presence on the parts joined is not to be detrimental to the functioning of these parts.

These secondary characteristics of the welds must also conform to certain standards as given in the following sections if the general quality of welding is to be considered good.

2. Weld Strength

The primary requirement of a spot weld is its ability to resist shear stress.

Since the exact strength of the joint depends on the quantity and pattern of all welds forming the joint as well as on the individual strength of each spot weld, the strength of each spot weld need not necessarily be an exact function of the size or gauge of the parts joined and thus two welds joining identical parts but possessing dissimilar shear strength may still be considered as entirely satisfactory.

Since, however, the strength of a joint and of a structure must perforce be measured in multiples of each spot weld forming the joint, it is of utmost importance that all spot welds constituting the joint should be of reasonably uniform strength or should at least possess a certain minimum strength if intelligent design is at all possible.

Practical experience as well as theoretical analysis indicates that to obtain always the requisite minimum strength an inherent stability of spot weld strength is necessary. This in turn is found to occur within a certain minimum and maximum range of average spot weld size and strength, based on the practical geometry of the weld in respect to the gauge thickness of the parts joined by the weld.

Accordingly, the first requirement of good spot welding made on a certain material thickness is to possess an average shear strength, as determined by the Standard Shear Pull Test, within certain fixed values given on Fig. 3.

The selection of the specific weld strength for a particular group of spot welds should be left to the discretion of the welding engineer and welding designer since it is frequently governed by the consideration of design and available equipment. Once it is selected, however, it should become the fabricator's strength standard for the job or part for which it was selected.

3. Strength Consistency

From structural point of view the fact that a weld may possess greater strength than the strength arbitrarily attached to it and used by the designer is of no objection. From practical consideration, however, a wide variation in strength of welds made under supposedly similar conditions is indicative of an unstable operating condition which may result in time in occurrence of welds of less than the desired design strength.

Therefore, for practical operating reasons, the second requirement of any series of spot welds made on the same material under supposedly identical conditions is to exhibit a maximum possible uniformity and strength consistency.

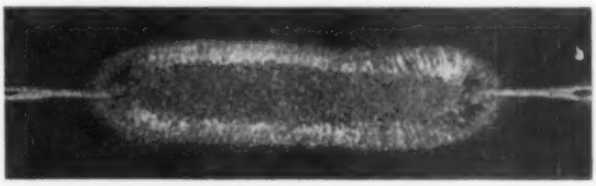
Since a great number of factors contribute toward the formation of a weld, a detrimental, from the point of view of strength, change in any one factor would affect the strength of the weld probably only to a small extent. However, a simultaneous adverse change in a number of factors may result in appreciable weakening of the weld strength. As the number of welds considered is increased the probability of such a simultaneous occurrence is increased and greater variation in weld strength can therefore be expected.

With the present operating methods it is reasonable to expect a variation of not over $\pm 10\%$ of the total average in 21 out of 25 consecutive welds with a variation of not over $\pm 20\%$ of the total average in the remaining four welds, as determined by the Standard Strength Consistency Test.

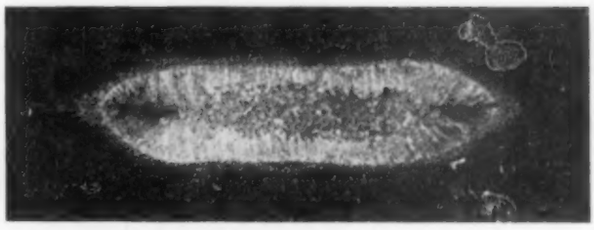
Since a definite relationship exists between the weld size and its strength, it is also reasonable to expect a comparable consistency in the weld size, or a variation of not over $\pm 10\%$ of the average of 15 weld diameters as determined by the Weld Consistency Check Test.

Therefore, *the second requirement of good spot welding shall be its ability to possess consistency of strength and size within the above limits.*

The average as exhibited by the Strength Consistency Test may be any value provided that it lies within the values given on Fig. 3 and is equal to or higher than the fabricator's particular strength requirement if and when such requirement is established.



24ST Alclad Sheet 0.051 to 0.051.



52S 1/2H Alloy 0.064 Thick.

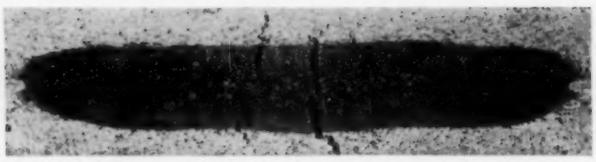
Fig. 4—Section Through Spot Weld Showing Satisfactory Weld Structure of Aluminum Alloys. Keller's Etch. X 10

4. Weld Metal Structure

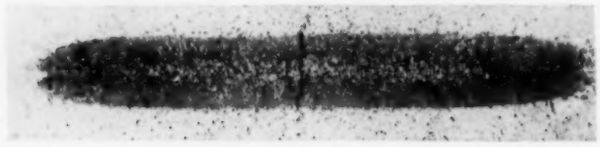
There appears to be definite evidence that severe cracks, that is, cracks extending beyond the weld metal proper or to the surface of the parts joined, lower the corrosion resistance of such welds and in addition may produce detrimental effect on the fatigue strength of the parts joined. It also appears certain that excessive cavities present inside a weld lower the strength of the weld and are indicative of an operating condition which may result in formation of welds of low or even zero strength. (See Figs. 5 and 6.)

Accordingly such cracks and cavities shall be considered as defects. Since, however, their effect is largely cumulative and their presence in small quantities does not usually endanger the performance of the structure, the occurrence of these defects in small quantities shall be permitted and shall not be considered as a reflection on the general quality of welding.

The presence of these defects shall be tolerated to the extent of 3% on structural parts and 6% on non-structural parts.



Severe Cracks Extending to the Surface of the Sheet.



Severe crack extending through the weld metal and into the parent metal. In the majority of cases the presence of such a crack can be detected from the surface of the weld and it will usually come through to the surface upon comparatively slight flexing of the sheet.

Fig. 5—Sections Through Defective 24ST Alclad Welds Showing Severe Cracks. Keller's Etch. X 8

There appears to be no conclusive evidence at this time that the internal cracks, that is, shrinkage cracks present in the weld metal which do not extend beyond the weld metal or the surface of the part joined, have any detrimental effect upon welds. Similarly, there appears to be no evidence that presence of porosity or small cavities have any detrimental effect upon the weld. Accordingly, and until evidence to the contrary is produced, the presence of such cracks and porosity in any amount shall not be considered as detrimental to or reflecting on the general quality of welding. (See Fig. 7.)

The permissible porosity shall be defined as presence of one or more cavities whose dimensions in any one direction shall not exceed 20% of the thickness of the thickest sheet joined or 10% of the total thickness joined, whichever is the largest.

In alclad materials it is occasionally possible to produce welds in which the pure aluminum of the cladding has not become diffused in the weld metal but is present in a thin layer usually parallel to the plane of the weld. The presence of such homogeneous layer of alcladding within the weld lowers appreciably the shear strength of the weld and therefore shall be considered as a defect unless the diameter of this layer as exhibited by the Weld Metal Structure Test is less than 20% of the diameter of the weld. The same is true of longitudinal cracks in the plane of joint which occasionally occur in spot welds. It must be remembered, however, that the significance of these structural defects lies in their tendency to lower appreciably the shear strength of the weld, and for this reason their presence would be usually detected by the Strength Consistency Test.

5. Weld Penetration

The penetration of the cast weld metal into the outer sheets of a joint is of primary importance since it bears a definite relationship to the weld strength consistency and to the presence of severe cracks extending to the surface of the sheets joined. Thus welds with penetration into either one or both of the two outer sheets of less than 20% of the thickness of the sheet as measured by the Standard

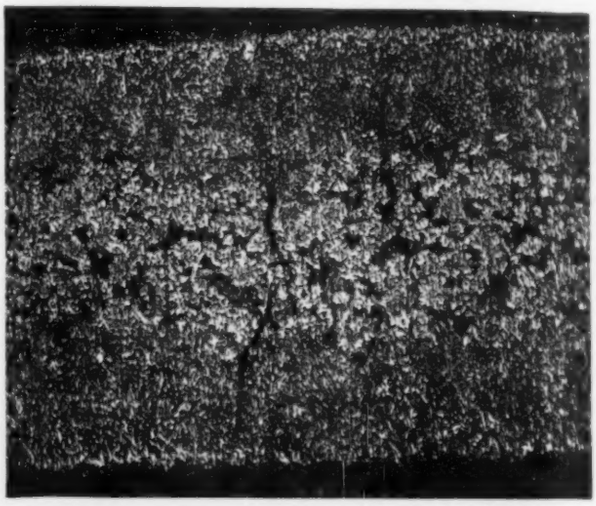
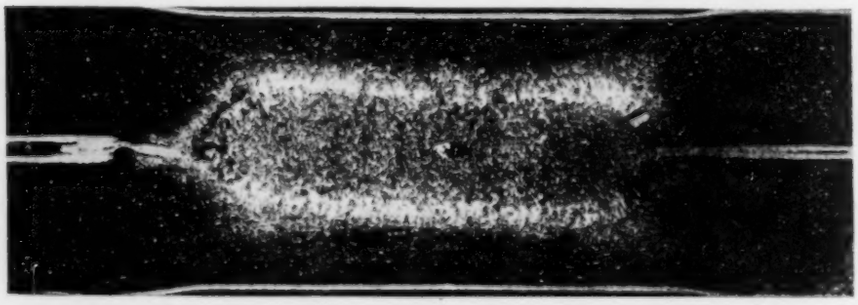


Fig. 7—Section Through 24ST Alclad Weld Showing Permissible Internal Cracks. Keller's Etch. X 50

An extreme case of metal expulsion causing large cavity and collapse of the weld wall. Traces of expelled metal can be seen adjacent to the weld between the faying surfaces.



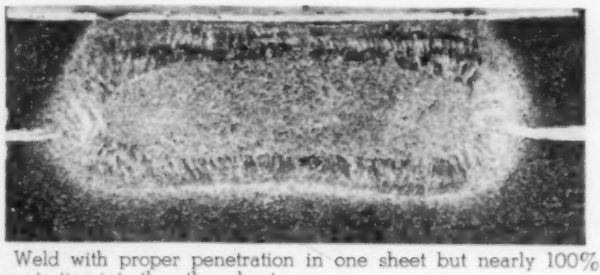
Severe cavity in the center of the weld, probably caused by expulsion of the metal, traces of which can be seen between the faying surfaces.

Fig. 6—Sections Through Defective 24ST Alcad Weld Showing Severe Cavitation and Metal Expulsion. Keller's Etch. X 10

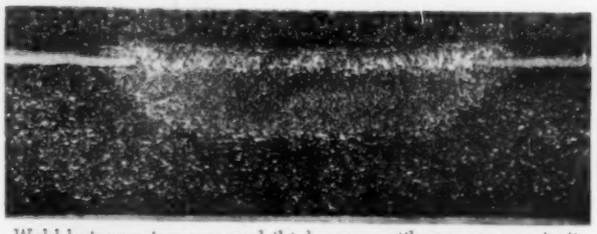
Weld Penetration Test or the Weld Metal Structure Test are indicative of an unstable operating condition where welds with less than minimum or even zero strength may be expected to occur. Similarly, welds with penetration into either one or both of the two outer sheets of more than 80% of the thickness of the sheet are indicative of an operating condition where severely cracked welds may occasionally result.

Accordingly, welds exhibiting penetration beyond the above range, as exhibited by the Weld Metal Structure Test or the Weld Penetration Test, though not in themselves defective, shall be considered as indicative of a poor welding technique and their presence shall be considered as condemning the general quality of welding. (See Fig. 8.)

If the penetration of the weld is different at any one part of the weld from the rest of the weld, as is true, for instance, in case of toroidal or doughnut-shaped welds, the penetration of that part shall be also within the limits prescribed above provided the area of that part as measured by the Standard Weld Penetration Test or the Weld Metal Structure Test is not less than 20% of the total weld area, in which case it can be disregarded.



Weld with proper penetration in one sheet but nearly 100% penetration into the other sheet.



Weld between two unequal thicknesses with proper penetration into one thickness but insufficient penetration into the other thickness. The strength of this particular weld is entirely satisfactory but a slight variation in welding condition may cause complete lack of penetration and it is, therefore, indicative of an unstable welding condition.

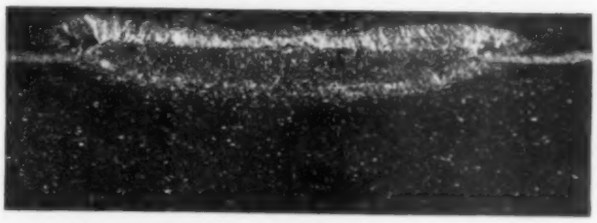
Fig. 8—Sections Through a Defective 24ST Alclad Weld Showing Improper Weld Penetration. Keller's Etch. X 10

6. Weld Symmetry

No conclusive evidence appears to exist at this time that symmetry in the vertical plane of the joint, that is, proportionately equal penetration into the outside sheets joined, is of any significance or advantage as long as the penetration into the sheets is within proper limits. Accordingly, the absence or lack of this symmetry shall not be considered as affecting the quality of the weld. (See Fig. 9.)

The absence of symmetry in the horizontal plane of the weld as exhibited by welds of irregular, star or cloverleaf area at the plane of the joint is indicative of either a variable contact resistance or of other unsatisfactory operating condition which may result in occasional occurrence of either low strength or severely cracked welds. Therefore, reasonable symmetry of the area at the plane of the joint should be exhibited by good welds, though the

Weld between two equal thicknesses with satisfactory, though unequal, penetration into each thickness.



Weld between two unequal thicknesses with satisfactory, though asymmetrical, penetration into each thickness.

Fig. 9—Sections Through 24ST Alclad Welds Showing Satisfactory, Though Asymmetrical, Penetration. Keller's Etch. X 10

exact shape of the area is of no particular significance and may be circular, oval or eliptical.

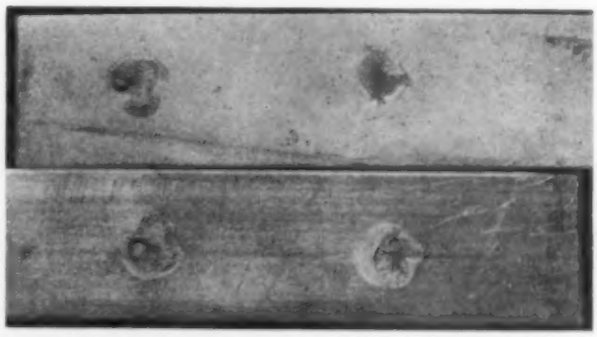
Presence of irregularly shaped welds as defined above in any appreciable quantity shall be considered as indication of a poor welding technique and shall condemn the quality of welding. (See Fig. 10.)

7. Surface Indentation

The surface indentation produced by a spot weld can be significant either because of its effect on the outside appearance and smoothness of the part joined or because of its effect on the separation or fit of the parts joined.

In aircraft structures parts with outside surfaces exposed to air stream require maximum of smoothness. It is, therefore, imperative that on such surfaces the indentation due to a spot weld does not exceed 0.004 of an inch.

An extremely deep indentation is usually indicative of excessive separation between the parts joined and is also indicative of an undesirable operating condition, the persistence of which may result in welds defective in other respects. Accordingly welds with surface indentation of 20% and over of the total thickness welded, if most of the indentation is confined to one side, or 10% and over if indentation is approximately equally distributed be-



A

Fig. 10—Section Through Plane of Joint of Welds Showing Irregularly Shaped Welds at the Plane of Joint, Probably Caused by Improper Surface Preparation

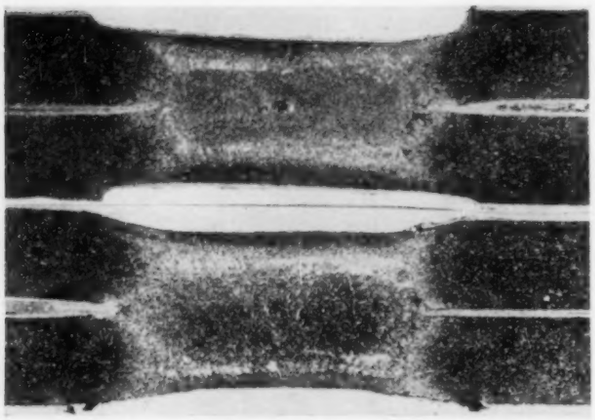


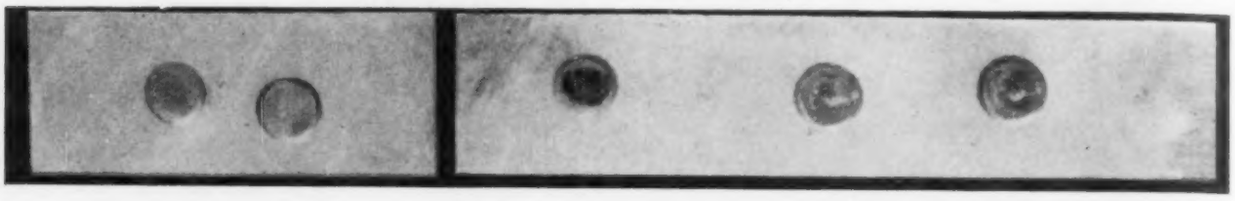
Fig. 11—Sections Through Defective Weld Showing Excessive Surface Indentation. Keller's Etch. X 6

tween the two sides shall be considered as unsatisfactory, and their presence in any appreciable quantity shall condemn the general quality of welding. This, of course, applies only to surfaces not exposed to air stream where only 0.004 of an inch indentation or less is considered satisfactory. (See Fig. 11.)

Indentations of irregular circumference or with the surface of the weld at an appreciable (obvious to visual observation) angle to the surface of the part welded are indicative of a poor operating condition and shall be therefore considered as unsatisfactory.

8. Surface Burning

The purpose of pure aluminum on the surface of the alclad alloys is to improve the corrosion properties of such alloys. Accordingly welds with the alclad removed from the surface of the weld from excessive heating or other causes shall be considered as unsatisfactory and the presence of such welds in quantities of over 3% on structural and 6% on non-structural parts shall be considered as condemning the general quality of welding.



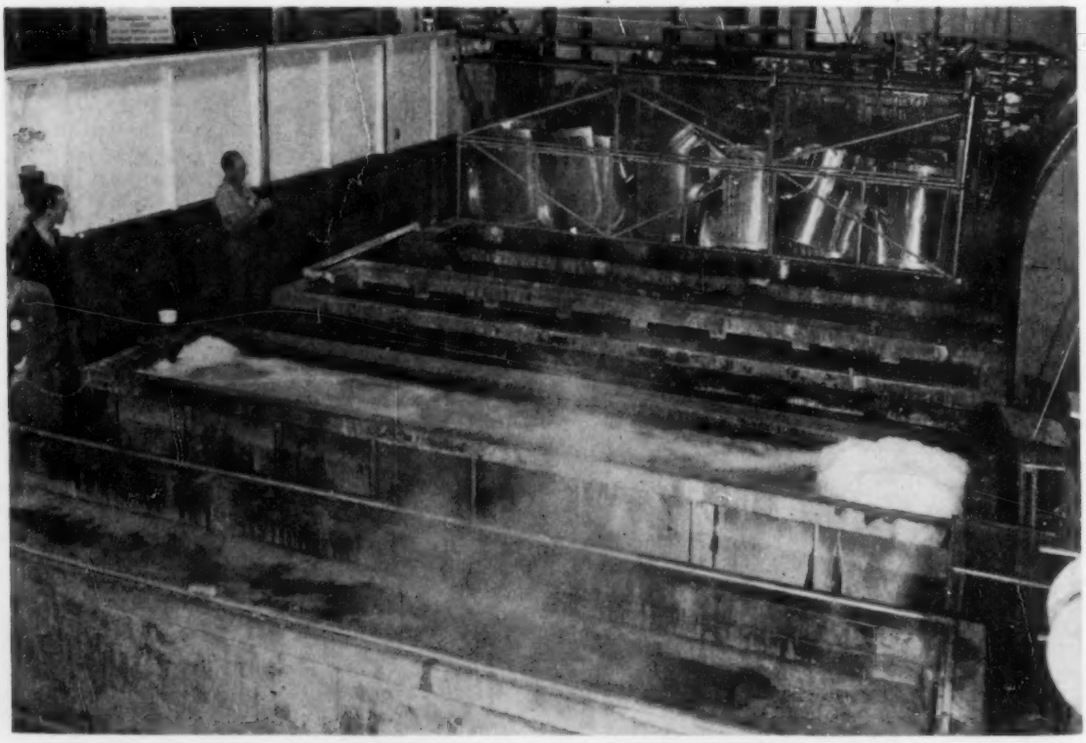
B

Weld surfaces resulting when electrode picks up aluminum.

C

Weld surfaces resulting when electrode material comes off and coats the spots.

Fig. 12—Surface of Spot Welds Made on 24ST Alclad Material Exhibiting Excessive Surface Discoloration and Pick-Up



Courtesy of Lockheed Aircraft Corporation

Fig. 13—Typical Installation for Chemical Treatment of Aluminum Alloys Prior to Spot Welding

Tanks contain suitable degreasing, rinsing, and etching solutions. Material is loaded into a hoist propelled stainless steel wire basket which immerses the material progressively into the different tanks.

In borderline cases where it is not obvious to visual observation that the alclad coating has been removed, the following test may be used for determining whether the base alloy has been exposed.

A few drops of standard Keller's etch solution (1.0% HF, 1.5% HCl, 2.5% HNO_3 and 95% water) shall be deposited onto the surface in doubt and allowed to remain for about one minute. If alclad coating is present a white spot will be obtained. If, however, the alclad coating has been removed, a brown spot will be noticeable. After the completion of the test the solution should be carefully washed off to prevent further attack of alcladding. The brownish deposit formed on the bare metal can be removed by washing the part tested with 50% by volume nitric acid solution.

Surface discoloration caused by either excessive surface heating or excessive electrode pick-up or deposit of electrode material may affect the corrosion properties of the weld and is also indicative of poor operating conditions and for this reason shall be considered as unsatisfactory. However, the presence of surface discoloration, in small quantities of not over 10%, shall be permitted and shall not be considered as condemning or reflecting on the general quality of welding. (See Fig. 12.)

9. Sheet Separation

Excessive sheet separation may frequently cause structural difficulties and should be considered unsatisfactory when and if it is in excess of 10% of the thinnest of the sheet joined when measured at the edge of the weld.

10. Cracked Edge Welds

Occasionally welds are placed so close to the edge of the sheets as to cause cracks in the sheet extending from the edge toward the weld. These welds belong to the same category as the welds with severe cracks extending to the surface and shall be treated as such.

11. Weld Flashes or Spits

Weld flashes or spits may occur on the surface of the weld or between the surfaces joined.

The first kind, namely, the surface flashes or spits, are usually caused by excessive local heating. Their presence has no particular bearing on the quality of the weld and shall not, therefore, be considered as a defect. They are, however, indicative of a poor operating condition and their presence in excess of 10% shall be considered as condemning the general quality of welding.

The internal flash, or flash occurring at the inside surfaces joined, is apt to produce excessive separation of sheets, may be indicative of presence of large cavities inside the weld, and in alclad alloys may lower the corrosion resistance of the joint by breaking the pure aluminum seal normally present around the weld at the joint. In addition, it is indicative of an unstable operating condition where excessive cavities and severe cracks may be expected to occur. For this reason its presence in quantities over 5% in primary and 10% in secondary structures shall be considered as condemning the general quality of welding.

12. Weld Spacing and Location

The location and spacing of the welds on the parts joined shall be in reasonable accord with the assembly drawings provided it is in accordance with the recommended design practices as given in Section VI of these Standards.

A tolerance of $\pm 1/8$ in. shall be allowed for all spot weld spacings.

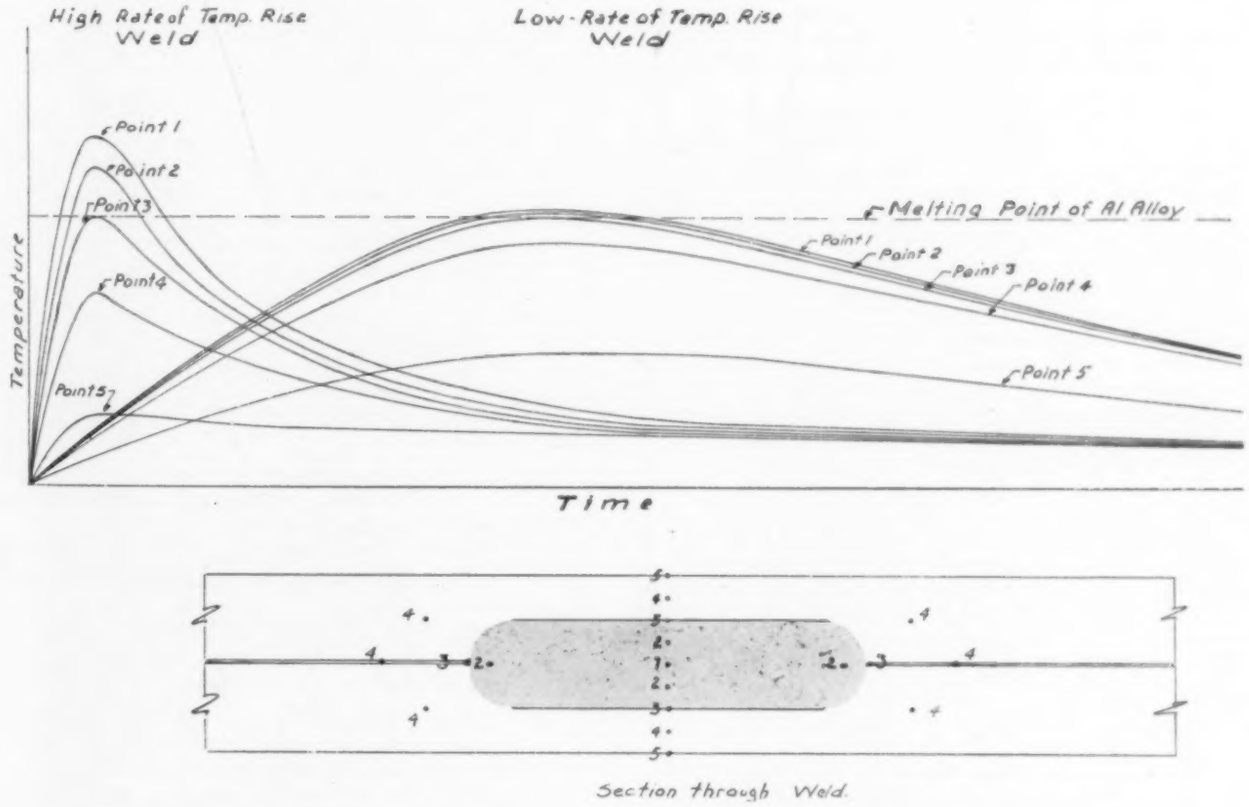


Fig. 14—Probable Time-Temperature Curves for Short Thermal Cycle and Long Thermal Cycle Welds

Section II—Material Preparation

All aluminum and aluminum alloys should be suitably treated prior to spot welding to expedite welding operation and to improve the quality of resulting welds.

1. *Purpose of Surface Preparation*

The purpose of pre-weld surface preparation of aluminum and aluminum alloys is to eliminate variations in the heat of welding due to variations in the contact surface resistance of unprepared aluminum sheets and to reduce to a minimum the heating between the aluminum sheet and the welding electrodes supplying current to the weld.

The surface resistance of aluminum sheets is caused by the presence on the sheet of foreign substances either deposited on the sheet in the course of handling or formed chemically by the action of atmosphere or other agents brought in contact with the sheet during fabrication.

It is important to realize that the mechanical and chemical films constituting the surface resistance are in no way similar and different methods must be used for the removal of each film.

Since the fundamental principle of spot welding is creation of fusion between the inner surfaces of the parts joined but not on their outside surfaces it is self-evident that heat produced between electrode surfaces and sheets welded can be only harmful, particularly so if surface marking of the sheets is to be avoided. In addition, since aluminum alloys readily alloy with copper, especially at higher temperatures, it is important that the temperature of the aluminum to copper contact remain as low as possible in order that the electrode surfaces remain clean and do not become contaminated with aluminum or other foreign material.

It is then imperative to remove both dirt and the oxide film from the surfaces of the parts welded coming in contact with the welding electrode to insure welds with good surface appearance and to minimize electrode pick-up, and thus increase electrode life.

The need of removing the resistance film between the surfaces being welded is equally great though at first not so apparent. It is evident that any mechanically deposited film such as oil, dirt, etc., cannot be uniform and therefore will introduce variation into the contact resistance and therefore into the amount of welding heat generated, which in turn will vary the extent of fusion. For this reason this film must be removed. The chemical film of aluminum oxide present on all aluminum and its alloys is also non-uniform in character. In addition, it is frequently of such magnitude that a breakdown through the film requires an appreciable potential with the result that when it occurs, the passage of welding current is sharply localized to a few points which in turn results in excessive local heating, expulsion of weld metal from the weld, weld cavities, and irregularity in the shape of the welds.

Theoretically the contact resistance between the surfaces welded need not be reduced to zero but can remain at a certain uniform and preferably fairly low value. In practice, however, it is very difficult to reproduce this condition consistently and for all practical purposes the best procedure is to reduce the surface film to as low a value as possible.

2. *Ideal Surface Preparation Method*

The ideal surface preparation method would remove all mechanically or chemically deposited film from the surface without attacking the alloy proper or the aluminum cladding if this is present. In addition, the method should leave the surface protected with a uniform film of very low resistance, inhibiting the formation of oxide film which otherwise would begin to take place immediately the moment aluminum or its alloys are exposed to the atmosphere. The resistance of this protective film, however, must not be materially different from that of the alloy itself. A preparation of this kind will permit uniform length of time exposure for all gauge thicknesses, will not be critical to over exposure, and will permit welding several days after cleaning or as long as the protective film lasts.

No method providing all of these requirements is now known. There are, however, several methods which approach the first requirement with a fair degree of success. The actions of these methods are either chemical or mechanical and they, therefore, fall broadly into these two categories depending upon their method of attack.

3. *Available Methods of Surface Cleaning*

There are a number of means of removing the mechanically deposited film of dirt or oil from the surface of aluminum or its alloys. Any oil- or grease-dissolving operation combined with some form of mechanical agitation such as spraying or wiping action which results in positive removal of oil, grease and dirt is satisfactory. Vapor degreasers and chemical baths are the most satisfactory though with proper supervision and technique, hand wiping with acetone or alcohol, though less dependable, can be also satisfactory.

It must be remembered that the removal of foreign substances such as oil or dirt from the aluminum surface is not only necessary for its own sake but also in order to permit the subsequent removal of the oxide film since most of the means capable of attacking this film are rendered, to a large degree, ineffective by the presence of oil or grease, and will not operate unless the surface is *chemically* clean, that is, will support a water film.

4. *Mechanical Methods of Oxide Removal*

The chemically formed film of oxide present on all aluminum surfaces can be scraped off by any mechanical operation utilizing the abrasive action of steel wool, wire brush or any abrasive powder. The action must be sufficiently severe to cut through the oxide film yet gentle enough to prevent formation of an excessively rough or scratched surface. In the case of alclad alloys, the action must be sufficiently slow to guard against appreciable removal of the aluminum cladding. For this reason the bristles of wire brushes and the grade of abrasive must be sufficiently fine to produce comparatively slow removal of material with each application. In general, the bristles must not be over 0.004 in. in diameter and the abrasive not over No. 240 aloxite cloth.

The principal *advantages* of mechanical method of oxide removal are:

First—ability to completely remove the oxide film without any danger of subsequent deposit of any other high resistance film.

Second—ability to remove oxide film from any part of a surface without the need of treating the entire surface.

Third—very low, capital investment.

The principal *disadvantages* of the mechanical method of oxide removal are:

First—high unit labor cost since steel wool, wire brush or abrasive must be applied to the surface by hand and since the removal is comparatively slow.

Second—difficulty of insuring uniform action by the operator since the extent of removal depends on the force applied by the operator to the rotary brush or

abrasive sander or steel wool pad and the length of application of these means by him to any one spot.

5. *Chemical Means of Oxide Removal*

There are a number of chemical agents which will attack the aluminum oxide film and thus free the aluminum surface from it. Unfortunately, however, most of these agents, after removing the film, will attack the metal itself though a few will not attack some specific aluminum alloys such as, for instance, 52S.

In chemical cleaning, therefore, time of exposure to the action of the oxide removing chemical is of great importance as the resistance of the films deposited on the aluminum surface, by the subsequent action of the agents, are frequently of the same order of magnitude as the original oxide film removed by them. (See N.A.C.A. Report No. 3 on Spot Welding Investigation at Rensselaer Polytechnic Institute.)

Hydrofluoric acid of usually three per cent by volume concentration is probably the most powerful agent for attacking aluminum oxide film. Unfortunately the action of this acid on the material itself is just as violent and therefore the operation, although very fast, is very critical and must be done with extreme care.

Sodium hydroxide (caustic soda) is another powerful agent attacking aluminum oxide. However, it attacks the material itself even more rapidly than the oxide film, forming a high resistant deposit so that its use also is dangerous and very critical in so far as time is concerned. In addition, because of the faster action on the aluminum than on the oxide, the resultant surface is apt to be non-uniform and of varying resistance. For this reason, although it was one of the first agents to be tried, its use is *not recommended* for spot welding.

Mild acids with sulphur basis appear to be in some ways superior to other forms of oxide removal chemicals since their action is slower and the time of their application much less critical. Of those the preparations of the type of Oakite 84-A Solution appear to be the best at this time. They attack the oxide film comparatively rapidly and their action on the material itself after the removal of oxide is considerably delayed so that an appreciable tolerance in the time of exposure can be permitted.

The usual method of application of chemical oxide removers is by immersion of the surface to be welded into the solution stored for this purpose in suitable corrosion-resistant tanks. The immersion may be done manually by the operator or by means of a hoist-operated basket.

An alternative method is by suspending the agent in a jelly or paste such as, for instance, a solution of gum tragacanth in water, which is then spread or smeared on the surface to be cleaned. This method does not lend itself easily to accurate control, is messy and slow in application, and for these reasons has been almost universally abandoned.

The principal *advantages* of the chemical method of cleaning are:

First—extreme uniformity of results and ability to reproduce consistently the same surface condition—provided proper process control is exercised—independently of the skill of any individual operator.

Second—low unit labor cost since with proper installation the only labor cost is in loading and unloading of the cleaning basket.

The principal *disadvantages* of the chemical method of cleaning are:

First—necessity to control accurately the time of exposure of the surface treated to the action of the agent used, since either over- or under-exposure will result in higher surface resistance.

Second—presence of corrosive acids or alkalies on the factory floor and their potential danger to the operator.

Third—comparatively elaborate installation including corrosion-resisting tanks, automatic temperature and time control, hoists, dipping baskets, etc.

6. *Most Common Methods of Cleaning*

On Tables 1 to 4 are given the methods of cleaning which are at present most commonly used. Although these methods are the best that appear to be now available, none of them are completely satisfactory and it is hoped that better methods will be developed in the near future.

It must be remembered that consistency and uniformity of the resistance of the prepared surface are of the utmost importance, and that this consistency and uniformity can only be obtained if the entire process of surface preparation is treated in a series of well-designed and controlled steps with proper provisions for prevention of further contamination of the surfaces treated during the process from any outside source whatsoever or through accidental reactions of the different agents used, on each other. This in turn means that application of each agent must be followed at the earliest possible time with operations designed for their complete removal from the surfaces treated. Thus in mechanical oxide removal all traces of shredded steel wool must be completely wiped off the surface and the cleaning material such as acetone or chemical cleaner must be carefully dried off or rinsed off with water, respectively. Similarly all chemical cleaning and oxide removal operations must be followed immediately by thorough rinsing in water and complete and rapid drying by means of hot air blast or the use of extremely hot water.

In chemical methods, time of exposure and temperature of the solution should be controlled automatically. In mechanical methods the effort and performance of the operator must be rigorously supervised, and continually checked and inspected.

It must also be remembered that as soon as the surface is prepared for welding the chemical action of the atmosphere and the mechanical action of the deposition of dirt begin to undo the work performed during the surface preparation. For this reason the welding should be conducted as soon as practical after the surface preparation. In general, the surfaces prepared should be welded within 24 hr. Greater time intervals between preparation and welding frequently result in sufficient difficulties with electrode maintenance and weld quality to justify a revision in the routing and assembly procedure.

In general the advantages of chemical methods can best be realized in comparatively large installations where at least four or five spot welding machines are used. Conversely, the disadvantages of the mechanical method are least in a comparatively small installation, where cost differential would be at a minimum and the skill and performance of the few operators required are much easier to check and, therefore, to insure.

7. *Conclusion*

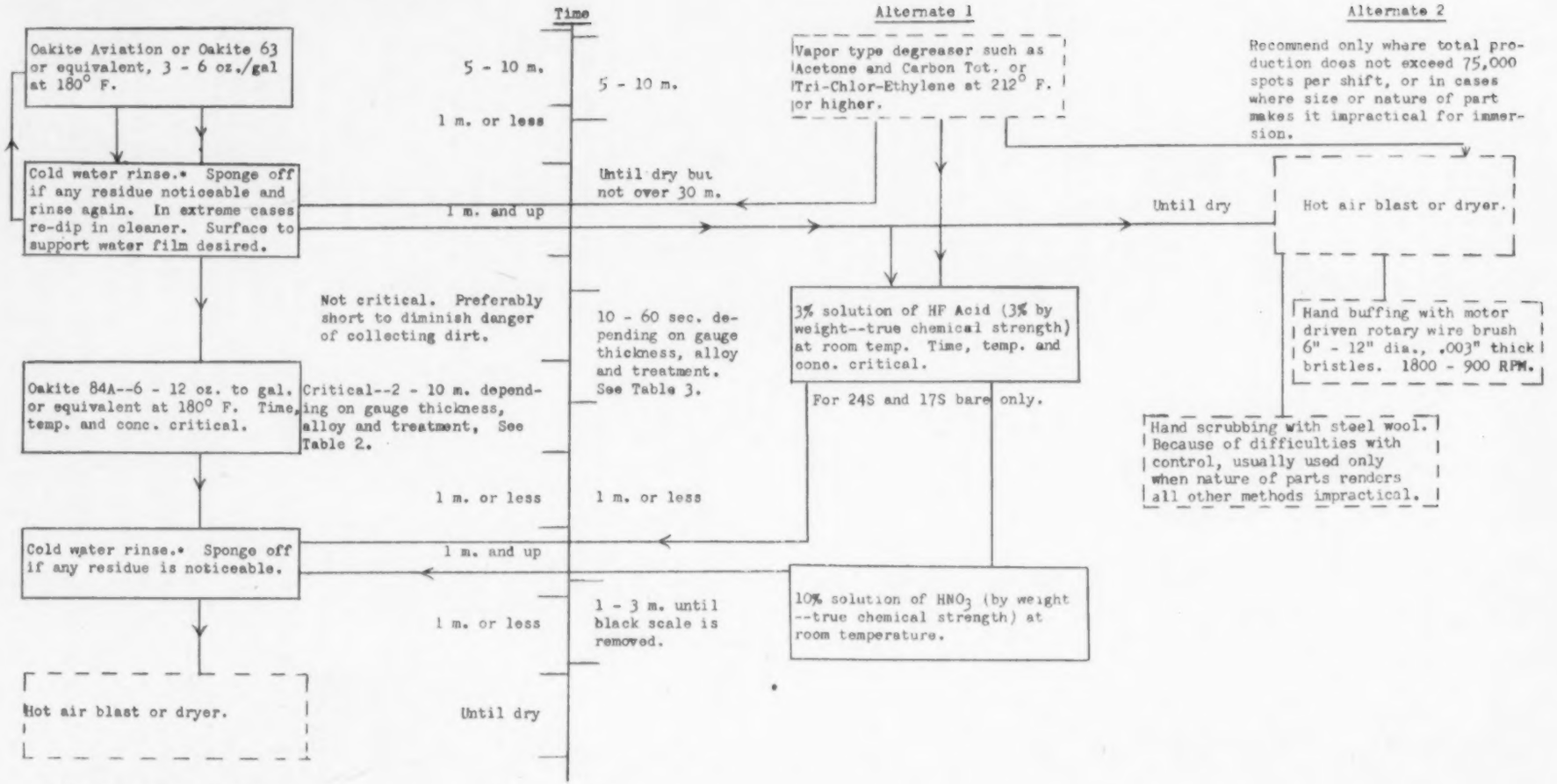
Enough emphasis cannot be placed on the importance of properly controlled and operated surface preparation plan. Although other factors enter as well, it appears that at least 75% of the troubles experienced with surface spitting, weld spitting, irregularity in weld shape and the extent of electrode pick-up can be attributed to improper surface preparation.

Table 1

MATERIAL PREPARATION

▭ represents complete immersion.
▭ represents operation other than immersion.

2S, 3S, 17S Alclad, 24S Alclad, 52S, 53S >80% <20%
24S, 17S sheet and extr.


Time
Alternate 1
Alternate 2
Oakite Aviation or Oakite 63 or equivalent, 3 - 6 oz./gal at 180° F.
5 - 10 m.
5 - 10 m.
Vapor type degreaser such as Acetone and Carbon Tet. or Tri-Chlor-Ethylene at 212° F. or higher.
Recommend only where total production does not exceed 75,000 spots per shift, or in cases where size or nature of part makes it impractical for immersion.
1 m. or less
Cold water rinse.* Sponge off if any residue noticeable and rinse again. In extreme cases re-dip in cleaner. Surface to support water film desired.
Until dry but not over 30 m.
1 m. and up
Until dry
Hot air blast or dryer.
Not critical. Preferably short to diminish danger of collecting dirt.
10 - 60 sec. depending on gauge thickness, alloy and treatment. See Table 3.
3% solution of HF Acid (3% by weight--true chemical strength) at room temp. Time, temp. and conc. critical.
Hand buffing with motor driven rotary wire brush 6" - 12" dia., .003" thick bristles. 1800 - 900 RPM.
Oakite 84A--6 - 12 oz. to gal. or equivalent at 180° F. Time, temp. and conc. critical.
Critical--2 - 10 m. depending on gauge thickness, alloy and treatment, See Table 2.
For 24S and 17S bare only.
Hand scrubbing with steel wool. Because of difficulties with control, usually used only when nature of parts renders all other methods impractical.
1 m. or less
1 m. or less
Cold water rinse.* Sponge off if any residue is noticeable.
1 m. and up
10% solution of HNO_3 (by weight --true chemical strength) at room temperature.
1 m. or less
1 - 3 m. until black scale is removed.
Hot air blast or dryer.
Until dry

* This operation is of utmost importance and should not be omitted under any circumstances.

Table 2—**Time of Immersion of 24ST Alclad Aluminum Alloy for Removal of Oxide Film in 3% by Weight Solution of HF Acid at 60–90° F. Temperature**

Metal Gauge	Time
0.016	20 seconds
0.020	25 seconds
0.025	30 seconds
0.032	35 seconds
0.040	40 seconds
0.051	45 seconds
0.064	50 seconds
0.072	55 seconds
0.084	60 seconds

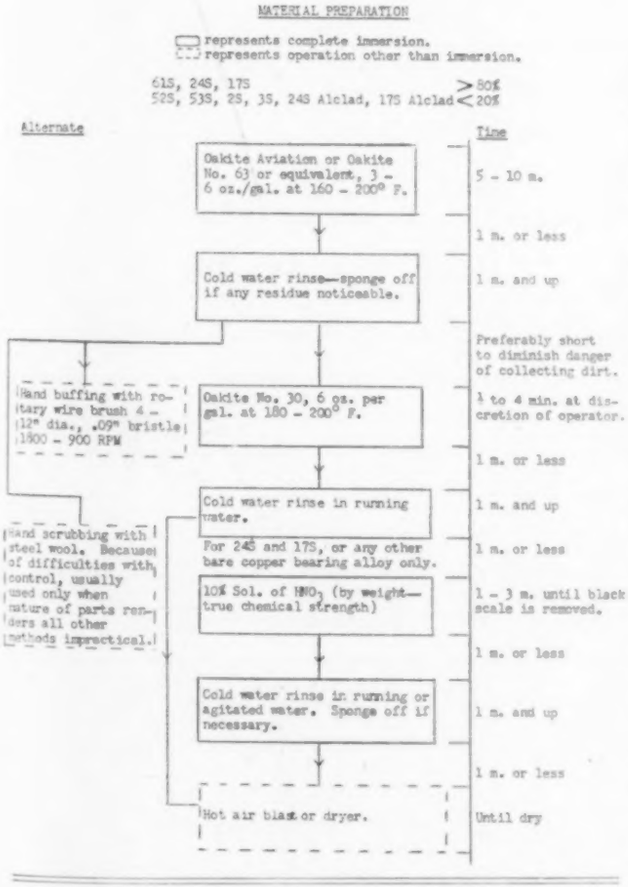
The time of immersion must not deviate from the above frequency by more than ±2 seconds.

Table 3—**Time of Immersion of 24ST Alclad Aluminum Alloy for Removal of Oxide Film, in 6 Oz. to 1 Gal. Solution of Oakite 84A or Equivalent at 180° F. Temperature**

Metal Gauge	Minimum Time	Maximum Time
0.016	2 min.	4 min.
0.020	2 min.	4 min.
0.025	2 min.	4 min.
0.035	2 min.	5 min.
0.040	2 min.	5 min.
0.051	2½ min.	6 min.
0.064	2½ min.	6 min.
0.072	3 min.	7 min.
0.084	3 min.	7 min.

Any length of immersion within the above ranges is satisfactory.

Table 4


MATERIAL PREPARATION
represents complete immersion.
represents operation other than immersion.
61S, 24S, 17S
52S, 53S, 2S, 3S, 24S Alclad, 17S Alclad
> 80%
< 20%
Alternate
Time
Oakite Aviation or Oakite No. 63 or equivalent, 3 – 6 oz./gal. at 160 – 200° F.
5 – 10 m.
1 m. or less
Cold water rinse—sponge off if any residue noticeable.
1 m. and up
Preferably short to diminish danger of collecting dirt.
Hand buffing with rotary wire brush 4 – 12" dia., .09" bristle 1800 – 900 RPM
Oakite No. 30, 6 oz. per gal. at 180 – 200° F.
½ to 4 m. at discretion of operator.
1 m. or less
Cold water rinse in running water.
1 m. and up
Hand scrubbing with steel wool. Because of difficulties with control, usually used only when nature of parts renders all other methods impractical.
For 24S and 17S, or any other bare copper bearing alloy only.
1 m. or less
10% Sol. of HNO3 (by weight—true chemical strength)
1 – 3 m. until black scale is removed.
1 m. or less
Cold water rinse in running or agitated water. Sponge off if necessary.
1 m. and up
1 m. or less
Hot air blast or dryer.
Until dry

Section III—Welding Technique

1. *Definition*

Although in a broad sense welding technique covers all operations pertaining to joining of parts by welding, it will be arbitrarily assumed herein to apply to that part of the welding process which deals directly with the use of the welding apparatus to produce a weld. In other words, welding technique will denote the ability to adjust and control the operation of the welding machine to produce welds of desired strength and quality.

2. *Electrode Shape and Maintenance*

(*a*) *Contour of Electrode Tip.*—The proper contour of electrode surfaces in contact with the parts being welded is a function of the thickness of the parts and of the type of welding process being used. It is also a function of the surface appearance desired and of the distribution of the weld indentation between the two sides of the weld. It is frequently also a function of the rigidity of the welding arms and of the accuracy of alignment of the top and bottom electrodes.

By making certain assumptions and approximations, a number of welding operations can be satisfactorily performed with electrodes possessing identical surface contours.

The principal assumptions usually made are:

First—that it is desired to concentrate most of the weld indentation on one side only, leaving the other side as free from weld indentation as possible.

Second—that a slight amount of misalignment of electrode tips and deflection of the electrode arms during welding will be encountered and must be tolerated in production.

To satisfy those conditions it is recommended that one of the two electrodes be made either perfectly flat or with a curvature so slight as to render it in effect flat (10 in. R or more), and that the other electrode be shaped to a certain radius as given in Table 5, depending on the gauge of the material being welded. It is further recommended that the electrode of the greatest practical diameter be used whenever possible.

The electrode contour should be maintained substantially the same throughout the welding operation except that on the domed or sharply radiused electrode, a flat, not appreciably greater in diameter than the diameter of the resultant weld, can be allowed to exist after such flat spot forms as the result of welding operation.

(*b*) *Method of Electrode Cleaning and Maintenance.*—It has been long customary in certain forms of spot welding to shape the electrode tip by hand in the machine by means of a file. This practice should be discouraged in aluminum welding since the quality of the weld is more sensitive to the electrode contour than in other forms of welding, and since results obtained by hand shaping are perforce very crude and inaccurate.

With proper surface preparation and with proper electrode water cooling as well as with the use of suitable electrode alloys, a normal welding electrode should be capable of maintaining its shape sufficiently to permit continual operation of not less than between four to eight hours or a total of 2000 to 5000 welds depending on gauge thickness and speed of operation. As soon as the electrode shows signs of wear or change in contour it should be replaced with a new electrode and its restoration to the original contour should be made on a lathe or by means of a special electrode shaping tool applied to the electrode while the electrode is still in the holder, provid-

Table 5—Recommended Electrode Contour

Electrostatic	Electrode Diameter in In.			Electromagnetic
For the top or the movable electrode				
0.016	2 in. R	5/8	7/8 1 1/4	3/4 in. R
0.020	2 in. R	5/8	7/8 1 1/4	3/4 in. R
0.030	2 in. R	5/8	7/8 1 1/4	2 in. R
0.040	2 in. R	5/8	7/8 1 1/4	2 in. R
0.050	2 in. R	5/8	7/8 1 1/4	2 in. R
0.064	4 in. R	5/8	7/8 1 1/4	4 in. R
0.072	4 in. R	5/8	7/8 1 1/4	4 in. R
0.080	4 in. R	7/8	1 1/4 1 1/2	4 in. R
0.093	4 in. R	7/8	1 1/4 1 1/2	.. in. R
0.109	4 in. R	7/8	1 1/4 1 1/2	.. in. R
For the bottom or stationary electrode				
0.016–0.109	10 in. R or flat	5/8	7/8 1 1/4	10 in. R or flat

Table 6—Average Number of Spot Welds Between Cleaning of Electrodes That Can Be Expected in Production

Material	Gauge Combination	Type of Equipment	Number of Welds
24ST Alclad	0.025 to 0.025	Alternating current	50
	0.040 to 0.040		40
	0.064 to 0.064		20
	0.025 to 0.025	Stored energy, electromagnetic	75
	0.040 to 0.040		45
	0.064 to 0.064		25
	0.025 to 0.025	Stored energy, condenser discharge	140
	0.040 to 0.040		90
	0.064 to 0.064		45
52S, 53S, 24S formed and heat treated	0.025 to 0.025	Stored energy, electromagnetic	25
	0.040 to 0.040		25
	0.064 to 0.064		20
52S, 53S, 24S formed and heat treated	0.025 to 0.025	Stored energy, condenser discharge	50
	0.040 to 0.040		45
	0.064 to 0.064		25

ing the performance of this tool is to all purposes indistinguishable from that of a lathe.

Under the present welding conditions it is necessary to keep the electrode surface clean and free from aluminum pick-up by hand dressing operation performed periodically.

This cleaning operation should be sufficiently light to prevent removal of any appreciable amount of electrode material or any appreciable change in electrode contour. A steel or aluminum paddle with a thin rubber cushion against the dome side and covered with No. 240 to No. 320 aloxite cloth can be used successfully for cleaning the electrode surface, when clamped between the electrodes at light "cleaning" pressure and rotated a few times.

Too frequent cleaning in some ways is as undesirable as too infrequent cleaning. In general the safe number of spot welds between cleanings should be 70 to 80% of the number of welds the tip is capable of making without surface roughness or discoloration beginning to appear on the spot welds. A less frequent cleaning will result in rapid deterioration of the electrode. A more frequent cleaning will unnecessarily slow down the welding speed and will also tend to decrease the electrode life.

Besides the surface preparation, the causes contributing to the excessive electrode pick-up and wear are the ones tending to raise the contact resistance of the elec-

Table 7—Spot Welding Schedule

Alternate Current Equipment

Machine No._____

Machine Make_____

Machine Rating_____KVA

Method of Surface Preparation_____

METAL AND GAUGE COMBINATIONS Top	Bottom	WELD SHEAR STRENGTH	WELD BUTTON DIA.	ELECTRODE DIA. AND RADIUS Top	Bottom	DISTANCE BETWEEN ARMS	THROAT DEPTH	WELD TIME	HOLD TIME	% PHASE CONTROL OR HEAT NO.	GAUGE PRESSURE LBS.	* ELECTRODE-PRESSURE IN LBS.	R.M.S. SECONDARY CURRENT

* For welding engineer records only.

Table 8—Spot Welding Schedule

Stored Energy Equipment—Electromagnetic Type

Machine No._____

Machine Make_____

Machine Rating_____ Method of Surface Preparation_____

METAL AND GAUGE COMBINATIONS Top	Bottom	WELD SHEAR STRENGTH	WELD BUTTON DIA.	ELECTRODE DIA. AND RADIUS Top	Bottom	DISTANCE BETWEEN ARMS	THROAT DEPTH	PRIMARY CURRENT	RESISTANCE BLOCKS IN CIRCUIT	SQUEEZE PRESSURE LBS.	TIME	WELD PRESSURE LBS.	TIME	FORGE PRESSURE LBS.	TIME	PEAK SEC. CURR.	TIME TO REACH PEAK SECONDARY CURRENT	* TIME TO DECAY TO 10% OF PEAK SECON. CURR.

* For welding engineer records only.

trode. Of these, the electrode material and electrode operating temperature are probably the most important. In general any electrode material possessing electrode conductivity of less than 85% of that of pure copper is unsatisfactory. Also, in general, the welding electrodes should not be allowed to reach a temperature in excess of 60° F. except momentarily at the instant of the formation of the weld. Under no conditions should the outside temperature of the cylindrical wall of the electrode be allowed to reach a temperature over 90° F. even momentarily.

The above recommendations are only approximate. They represent conditions which can be easily met in production with reasonably good water cooling and with use of electrodes of reasonable diameter. It is, of course, understood that special applications requiring the use of extremely narrow or poorly water-cooled electrodes may result in entirely different conditions. In those cases, however, very frequent dressing and poor electrode life must be expected.

With the use of precautions described above the normal frequency of electrode cleaning should not be greater than given in Table 6.

Considerably better electrode performance in so far as pick-up is concerned can be obtained with the use of pure copper. Unfortunately the change of contour experienced with the use of pure copper of Rockwell hardness of 50-B and less is such as to require constant attention and thus perhaps neutralize the advantages gained by lessened pick-up characteristics.

3. *Welding Schedules*

(*a*) *Definition, Type and Form.*—The term welding schedule will be used herein to denote the settings and adjustments of the welding machine required to produce a weld of desired strength and quality. Since different

Table 9—Spot Welding Schedule

Stored Energy Equipment—Electrostatic Type

Machine No._____

Machine Make_____

Machine Rating_____ Method of Surface Preparation_____

METAL AND GAUGE COMBINATIONS Top	Bottom	WELD SHEAR STRENGTH	WELD BUTTON DIA.	ELECTRODE DIA. AND RADIUS Top	Bottom	DISTANCE BETWEEN ARMS	THROAT DEPTH	PRIMARY VOLTAGE	NO. CONDEN. @ _____ MFD.	COND. SWITCH SETTINGS	SQUEEZE PRESSURE LBS.	TIME	WELD PRESSURE LBS.	TIME	FORGE PRESSURE LBS.	TIME	PEAK SECON. CURR.	TIME TO REACH PEAK SECONDARY CURRENT	* TIME TO DECAY TO 10% OF PEAK SECON. CURR.

* For welding engineer records only.

types of equipment require different adjustments and control the form of the welding schedule will vary, depending on the type of welding apparatus used. In addition the variables, the control of which the schedule purports to indicate, can be described in terms of the input to the machine such as primary current or primary voltage and pounds of air pressure into the machine, or in terms of the output of the machine such as secondary current and pound force at the welding tip.

The exact form of the welding schedule will then perforce vary, depending on the apparatus and the particular conditions existing in the fabricator's plant. Tables 7 to 9 give an arbitrary form and it is recommended that for the sake of uniformity this form be used. Whatever the form used, the welding schedule should always contain sufficient data to definitely tie down the setting or adjustment of every variable which is provided on the machine and which can be changed by the operator.

(*b*) *Establishment and Use of Welding Schedules.*—With proper process control established for all phases of welding it is possible and practical to duplicate from day to day on any one machine results obtained previously with certain machine settings. Thus it becomes possible to establish certain optimum welding schedules for welds of certain desired properties.

Since uniformity and consistency are probably two of the most important requirements of welding it is strongly recommended that the settings of welding equipment be not left to the discretion of the individual operator or leader but should be established once and for all by the cooperative efforts of welding engineer and production supervisor and the welding operation be then required to be conducted in accordance with this established schedule.

This procedure not only insures uniformity of results but also tends to draw attention to any variation or difference in the entire welding process as soon as any tendency for such difference appears. Thus, as soon as it becomes difficult or impossible for the operator to reproduce welds of certain predetermined quality with the prescribed welding technique, a definite indication is obtained of change either in the surface preparation of the material or in the material itself, or in the operation of the welding equipment, any one of which changes, unless it is satisfactorily analyzed and provided for, may constitute a continuous hazard to weld quality and consistency.

Since difference exists in the operation of individual machines even of identical rating and type, each machine should have its own welding schedule covering the operations normally conducted on this machine displayed conspicuously at or near the machine and no attempt should be made to operate one welding machine from a schedule intended for another machine even though the two may be of the identical type and rating.

In addition, any possible change in the accessories used on the machine such as different arms, different fixtures and jigs as well as any necessary adjustments in the geometry of the machine arms or electrode holders should be considered in the preparation of the welding schedules and, if necessary, different schedules provided for operation of equipment under different conditions.

To provide for the variations in the process control falling within the practical tolerances of each operation, a deviation from the established schedule of one of the variables should be allowed, provided that this deviation does not exceed $\pm 10\%$ of the variable chosen. The exact extent of permissible deviation will depend on the particular operation and on the process control tolerances established by the fabricator.

It is, therefore, recommended that each fabricator establish and enforce a permissible percentage of deviation from the welding schedule, which the operator can exercise at his own discretion.

Similarly, the variable chosen is best determined by each fabricator by himself since the choice will be dictated by conditions which may not be the same in each plant.

In general it appears that a deviation not to exceed $\pm 10\%$ in the adjustment of the welding current is the most practical to be left to the discretion of the operator with all other variables fixed.

(*c*) *Responsibility for Use of the Welding Schedule.*—It is recommended that the responsibility for the use of the proper welding schedules be placed on the welding supervisor or foreman and that no deviation from the use of the proper schedule beyond the limits allowed by the schedule should be made without his knowledge and sanction. It is recommended that indiscriminate departure from the welding schedule settings by operators, leaders or setup men be made a serious offense subject to disciplinary action.

It is recommended that the schedule displayed at the machine be made to give the necessary information to the operator in the most direct form, that is, in a form which would entail the least difficulties on his part in translating the intended welding technique into the actual machine settings.

However, in establishing and preparing proper welding schedules, it is recommended that proper welding technique for each gauge and materials combinations be first established in terms of the fundamental welding variables such as electrode contour and temperature, the magnitude, shape and duration of the welding current and the force or forces exerted by the electrodes on the weld during the weld cycle. These fundamentals, once established, will permit reproduction of identical welds on any machine operating on the same welding principle irrespective of type, rating or size. The task of preparing a suitable welding schedule for each individual machine can then be reduced merely to the determination of the proper settings and adjustments which in the machine under consideration will produce the desired secondary current and pressure output.

This procedure will greatly assist in utilizing the past welding experience in selecting and preparing schedules for additional and new equipment.

The determination of the welding fundamentals requires the use of instruments directly measuring the output of the welding equipment. The type and manner of use of such instruments are described in Section VII of these Standards dealing with welding equipment and its auxiliaries.

(*d*) *Welding Schedules Now in Use.*—The development of spot welding equipment is at present proceeding at such a rapid pace that recommendation of any set welding schedules would be impractical.*

4. Relationship Between Welding Technique and Weld Properties

(*a*) *General.*—In general it can be stated that proper process control—that is, proper control of *all* the factors entering into fabrication of parts and assemblies by spot welding, beginning with surface preparation, proper flange widths and proper fitting of parts—plays a more

* Tables A-4 to A-17 of the Appendix to this report and Appendix with the Tables represent welding schedules applicable to different types of equipment which are being used at this date in aircraft factories and therefore may be of assistance as a general guide or starting point in preparation or improvement of welding schedules applicable to any one fabricator. The report is on sale by the AMERICAN WELDING SOCIETY. Price $1.00

important part in the quality and consistency of the resultant welds than the welding technique alone. That is, with all process factors under proper control there is little difficulty in obtaining good welds with reasonably large number of welding techniques, as exemplified by different types of welding equipment and different machine settings.

Nevertheless, the importance of selecting proper welding schedules must not be underestimated as although satisfactory welds can be made as mentioned above with a number of welding techniques, certain of them are considerably easier to use in production than the others.

In general, the proper welding schedules for any one particular job represent a compromise between the best possible internal weld structure, surface appearance, electrode life and consistency of weld strength. *Thus an excessive emphasis on complete freedom from internal cracks and porosity* may frequently result in a schedule which would tend to produce in production *a certain percentage of extremely weak welds or even of welds without true fusion*. Similarly, *an over-emphasis on weld strength* may result in presence of *welds with cracks extending to the surface of the material and excessive electrode pick-up*.

Some of the more fundamental aspects of the Relationship Between Weld Properties and Welding Technique are discussed briefly in the following sections.

(*b*) *Weld Strength*.—The size of the spot weld and therefore to a large extent its shear strength depend on both the amount of heat generated at the spot and the force applied by the welding electrode at the weld, though within certain limits, and usually at the expense of the general weld quality, variations in strength can be obtained by variations of welding current alone.

In general, sufficient heat to fuse a large area cannot be generated at the weld without expelling molten metal unless a correspondingly large restraining force is applied to the spot by the welding electrode. Thus to increase appreciably the shear strength of a weld it becomes necessary to increase both the welding current and the welding pressure. As increase in the welding pressure takes place, the pressure density in the electrode tip may increase to a point where permanent deformation at the electrode tip of the material being welded may take place due both to the high-pressure density and also to the surface heating caused by the excessive current density at the point of entry of the welding current into the material. It then becomes necessary to increase the area of electrode in contact with the work and thus decrease both the pressure and current densities at the point of entry of current into the material.

Thus the steps required to increase the weld volume and through it the shear strength of the weld can be summarized as follows:

First—increase in the magnitude of welding current.
Second—increase in the magnitude of the welding force and further increase in the magnitude of welding current.
Third—increase in the area of the electrode surface in contact with the weld with further increase of both welding force and current.

In materials where the electrical and the heat conductivities of the electrode and of the material welded are far apart, lengthening of the time of current application has substantially the same effect as increasing its magnitude. However, in materials such as aluminum alloys where the conductivity of the electrode and of the weld metal are comparatively nearly equal, the lengthening alone of the time of application of current beyond certain rather narrow limits does not increase to any appreciable extent the volume of the weld. This tendency is particularly true of the thin gauge combinations, with total thickness of the section welded under 0.100 in. It becomes progressively less pronounced as the thickness of the section welded increases, until at section 0.200 in. total thickness, increase in weld volume caused by time increase alone, though still not as great as in case of steels, for instance, is appreciable.

(*c*) *Strength Consistency*.—The causes governing presence of welds of extremely low or zero strength among apparently satisfactory welds are in general the ones which contribute to an excessively slow rate of temperature rise within the weld and thus low temperature gradient around the weld. Accordingly any one of the following may produce this tendency:

First—excessively low rate of current rise.
Second—welding current of excessively low magnitude and high duration.
Third—excessive heating of the material surrounding weld metal, and of the electrode tip, such as may be caused by unduly high or prolonged preheat current.

A further generalization can be made to the effect that any welding technique wherein the energy used for fusing the weld metal is but a small fraction of the total amount of energy generated at the joint before and during the fusion, is far more susceptible to occasional lack of fusion than the technique wherein the useful energy, that is, the energy necessary to transform the volume of metal constituting the final weld from wrought to cast state, is a substantial part of the total energy generated at the weld. Thus welds of very shallow penetration or welds of extremely small diameter as compared to the thickness of the parts welded and/or to the size of electrode tips used, as well as the long time low rate of temperature rise welds, will be unstable, as in any of them a small variation in the energy generated at the joint may make the difference between fusion taking or not taking place. (See Fig. 14.)

(*d*) *Weld Metal Structure*.—The structure of the fused cast zone which constitutes the weld proper is generally desired to be as free from porosity and cracks as possible.

In general, the factors tending to produce cracks and porosity are the ones which cause either an excessively rapid thermal rise inside the weld, or an excessively high rate of cooling, or an improper balance or timing of the mechanical forces acting on the weld during and after fusion. They can be summarized as follows:

First—excessively high rate of welding current rise.
Second—welding current excessively high in magnitude and short in duration.
Third—insufficient welding pressure either during the flow of current or immediately after its cessation, or both.
Fourth—insufficient cooling of the outside surfaces by the welding electrodes during the fusion.

A distinction should be made between a condition of an excessively rapid generation of heat in the weld without sufficient force applied to the outside of the weld to control the internal force of the expanding weld metal, which results usually in actual expulsion of at least a part of the molten metal from the weld, with subsequent cavities and cracks in and through the weld and a condition where improperly timed or insufficient welding pressure is applied to the weld after it has been formed, and at the time of the solidification of metal, which results in what appears to be shrinkage cracks.

The first phenomenon is well known and is common to all metals. It can usually be readily corrected by reducing the magnitude or the rate of rise of the welding current, or by increasing welding pressure throughout the weld.

The second, typical of aluminum alloys, is less well understood and requires a rather fine balancing between the magnitude of the welding pressure and of the rate of heating of the weld and the zone immediately adjacent to the weld. In general, the higher the welding pressure at the time of the weld solidification and the slower the rate of temperature rise and decay in the weld and around the weld, the less tendency there will be for cracks. Thus the welding techniques utilizing preheat or postheat currents or comparatively flat current waves, that is, techniques using comparatively long thermal cycle, are freer from internal or external cracks. On the other hand, welding techniques utilizing very rapid temperature rise in the weld with an extremely steep temperature gradient between the surface and the inside of the weld, are more susceptible to formation of weld cracks and porosity.

In general it is also true that higher welding pressure densities (electrode force per unit area of the weld) will produce welds with less tendency for cracks and porosity. However, the high-pressure density must exist as soon as solidification of weld metal begins to take place, and in techniques using low pressures during fusion and high pressures after fusion, the timing of the application of high pressure is as critical as its magnitude, too late an application resulting in cracks and porosity.

(*e*) *Heat-Affected Zone Around the Weld.*—The extent of the heat-affected zone around the weld proper, that is, of the partially fused wrought alloy surrounding the cast structure of the weld itself, depends to a large extent on the rate of temperature rise within a weld since it represents the effect of the heat conducted away from the weld proper or generated in the metal around the weld and not utilized in the transformation of the weld structure from wrought to cast metal. Accordingly, any welding technique which tends to slow down the rate of temperature rise in the weld and to diminish the temperature gradient between the weld and the surrounding material will result in the formation of the more extended and more severely heat-affected zone than the technique where the rate of temperature rise is exceedingly fast and the ratio of the total heat energy generated at the weld to the energy actually required to make the weld is low.

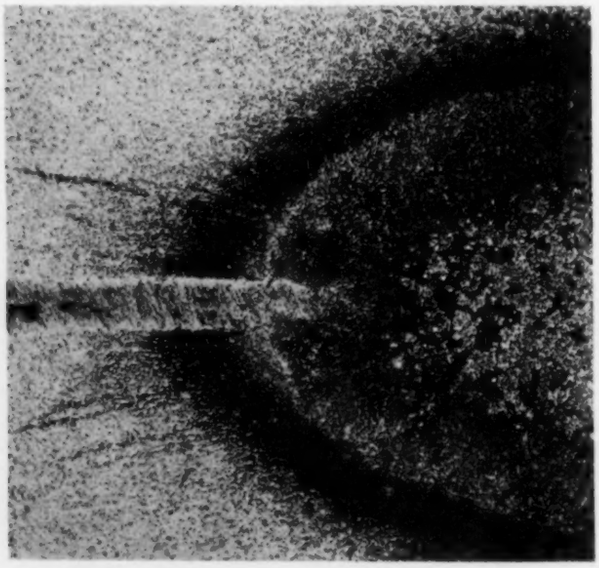


Fig. 15—Showing Extent of Heat-Affected Zone at the Edge of the Weld with Lines of Copper Precipitates Extending Outwards from the Weld and Parallel to the Plane of the Weld. Keller's Etch. X 40

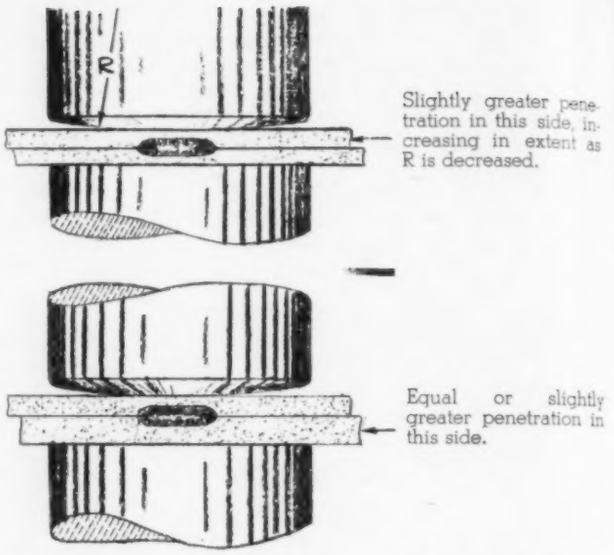

R
Slightly greater penetration in this side, increasing in extent as R is decreased.
Equal or slightly greater penetration in this side.

Fig. 16—Distribution of Weld Symmetry with a Flat and Dome Electrode. Material of Both Pieces Assumed to Be the Same

Thus the heat-affected zone in conventional A.C. welds is usually considerably greater than on single impulse welds and similarly welds made with preheat or postheat current exhibit a greater heat-affected zone than welds made without these currents.

(*f*) *Weld Penetration.*—The extent of weld penetration is usually a direct function of the magnitude of the current used at any one pressure. Thus an increase in welding current and to a lesser extent of the duration of the welding current will increase the thickness of the weld casting provided the pressure is held constant. Although from a structural point of view it is possible that increase in weld penetration may actually decrease the shear strength of the weld, particularly in welds with weld diameter of such magnitude as to cause failure through the periphery of the weld, a welding technique suitable for production of shallow welds with the total weld thickness of less than 30% of the combined thicknesses of the parts joined is seldom satisfactory in production as it is very sensitive to any variation in the welding process and is apt to produce occasional welds of very low or zero strength.

(*g*) *Weld Symmetry.*—Two forms of weld symmetry exist; first, symmetry in the horizontal plane of the joint and, second, in the vertical plane of the joint. The symmetry in the horizontal plane of the joint will automatically result with the use of symmetrically shaped electrodes and with uniform resistance between the surfaces being welded. Similarly, a non-uniform or irregularly shaped weld can be usually attributed to either irregularly shaped contour of the welding electrode or to improper surface preparation of the material.

The weld penetration in the vertical plane of the weld is a function of the surface contour of the two electrodes and of the relative thickness of the parts welded. It is to some extent also a function of the contact resistance of the surfaces being joined.

In general a deeper weld penetration will result in the sheet in contact with a smaller or more sharply domed of the two electrodes provided the two thicknesses being welded are equal and provided the resistance of the two thicknesses is the same. If the electrode contours are the same a greater penetration will take place in the thicker of the two outside thicknesses being welded and also in the one possessing highest resistance. It will thus be

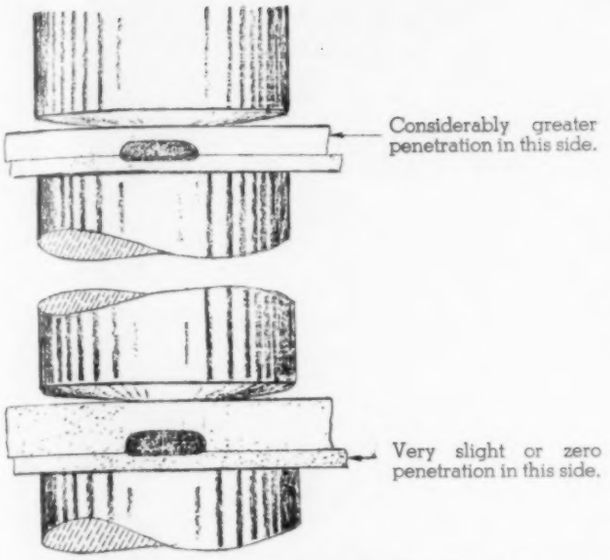


Fig. 17—Distribution of Weld Symmetry with a Flat and Dome Electrode. Material of Both Pieces Assumed to Be the Same

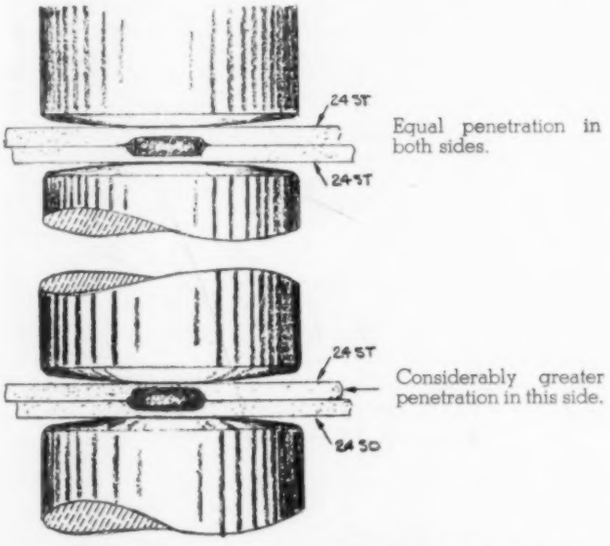


Fig. 18—Distribution of Weld Penetration with Two Equal Dome Electrodes

seen that it becomes impractical to weld with the dome point applied to the thicker of two outside thicknesses when the difference in thickness becomes appreciable, for instance three to one or more. (See Figs. 18 to 19.)

(*h*) *Electrode Pick-up and Surface Burning and Discoloration.*—Excessive electrode pick-up is usually caused by factors other than those of welding technique proper, such as improper surface preparation, improper electrode cooling or excessive skidding of the electrodes across the weld surface during the formation of the weld. However, any factor which tends to increase the amount of heat which the welding electrode has to conduct away from the weld will also tend to increase the electrode pick-up and thus decrease the useful life of the electrode. Thus welding techniques which tend to slow down the rate of temperature rise in the weld and thus increase the amount of heat which has to be conducted away from the weld by the electrode will have a tendency to cause a greater electrode pick-up than welding techniques which are based on very sharp temperature rise in the weld and a comparatively small loss of heat energy through the welding electrode.

The shape of the welding electrode, of course, and the conductivity of the material are also of paramount importance since any reduction in the cross section of the former and any decrease of the latter will have the same effect as increasing the amount of heat which the electrode has to conduct away, namely, in increasing the electrode temperature at the surface of the weld and thus increasing the electrode pick-up.

The surface burning and discoloration of welds are caused primarily by the same factors as excessive electrode pick-up, though, of course, welding techniques resulting in 100% or nearly 100% penetration will always cause surface burning. Surface discoloration and even

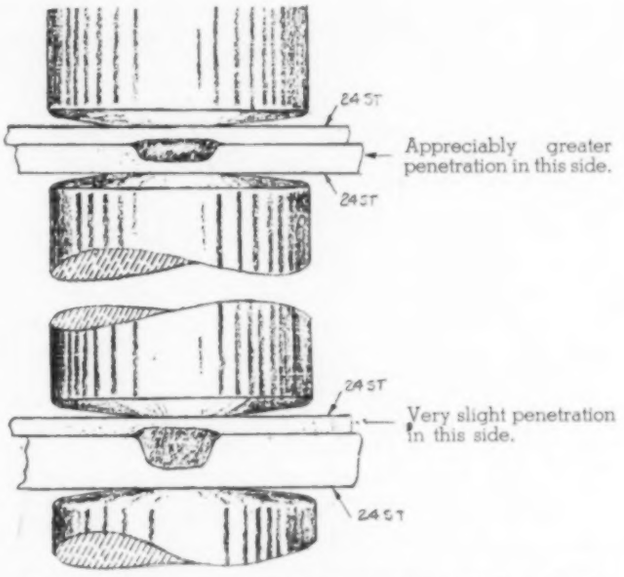


Fig. 19—Distribution of Weld Penetration with Two Equal Dome Electrodes

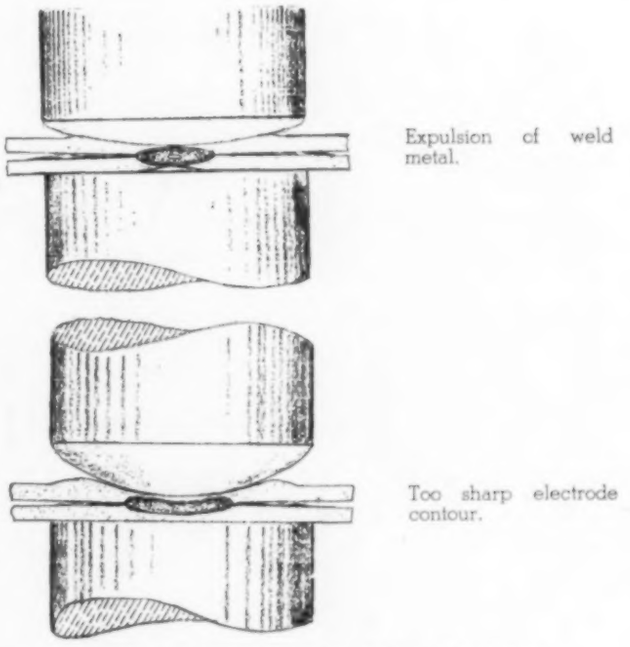


Fig. 20—Causes of Excessive Surface Indentation

burning are frequently caused by dirty or improperly cleaned electrodes operating at excessively high temperature. In extreme cases particles of electrode material may be even deposited onto the surface of the weld.

(*j*) *Surface Indentation.*—A certain minimum of surface indentation, caused by the shrinkage of weld metal, is unavoidable and must be expected if true fusion is to take place. The extent of this minimum indentation is directly proportional to the total thickness of the welded section and should not exceed approximately 5% of the total thickness. This 5% or minimum indentation may be divided equally between the two outside surfaces or may be largely confined to one surface, the other surface being correspondingly but never completely free from indentation, depending on the gauge combination joined and on the welding technique used.

Considerably greater indentation may be produced by:

First—any welding technique where improper pressure-current balance causes expulsion of weld metal from the weld in the form of internal flash or spit.

Second—improper electrode contour preventing application of sufficient pressure to the parent metal around the perimeter of the weld in the plane of the joint, and permitting plastic flow of metal into the space between the faying surfaces.

Third—excessive heating of the outside surface or surfaces of the parts joined, permitting plastic flow of metal from under the electrode face.

The effect of both the first and the second condition is to transmit the metal from the weld into the space between the faying surfaces and thus actually to decrease the cross section at the weld.

The first condition will, of course, also produce severe blowholes and usually surface cracks, and may in extreme cases produce deep pits or craters in the middle of the weld indentation.

The second condition also invariably produces considerable sheet separation which further aggravates the surface indentation by increasing the cross section of the joint outside and between the welds. It is usually caused by electrodes with too small a face or too sharp a radius for the diameter of the weld made or, since this in turn depends on both current and pressure, for the magnitude of the current and pressure used. Such electrodes frequently also produce excessive surface heating due to excessively high current density at the contact surface, between the electrode and the metal, and thus the second and third types of surface indentations are frequently found together. (See Fig. 20.)

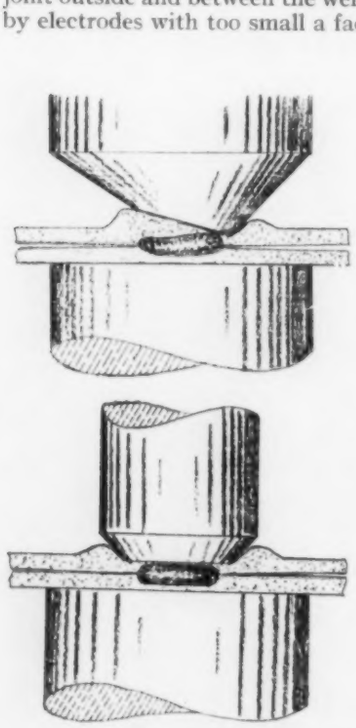


Fig. 21—Causes of Excessive Surface Indentation

The last condition may be caused by any of the many factors contributing to excessive surface heating, such as poor electrode cooling, dirty or improperly cleaned electrodes, excessive current and pressure density at the electrode face, etc.

Flat electrodes will almost invariably produce a slight surface plastic flow, unless, of course, the diameter of the face is very much greater than that of the weld, or unless the angle of approach to the face is very small.

This tendency of the flat-faced electrode is very much aggravated by even the slightest misalignment between the electrode and the surface to be welded, as any such misalignment will sharply reduce the contact surface between the electrode face and the part welded and cause considerable surface heating. (See Fig. 21.)

(*k*) *Sheet Separation.*—Excessive sheet separation—when it is not caused by factors outside of the welding technique such as poor fit of parts joined or insufficient width of flanges or overlap—can be usually attributed to the causes responsible for excessive surface deformation as described in the preceding section. In addition, in some cases it can also be caused by extremely high pressures at the time of fusion. This is particularly true in case of annealed alloys or pure aluminum. In general, soft metals are much more susceptible to surface separation and should be welded with lowest possible pressure. This is not surprising when we consider that though the expansion force of the weld metal is very nearly the same for soft as for hard metals, the ability of the parent metal around the perimeter of the weld to resist that force and escape plastic flow is very much less.

(*l*) *Weld Flashes and Spits.* In general, the factors contributing to formation of cracks in the welds will also tend to contribute to both internal and external spits or flashes though for a slightly different reason.

The internal flashes can be divided into two types.

The first is the type causing severe cavities and external cracks, where an appreciable part of the fused metal is expelled from the weld because the welding force is insufficient to provide weld-pressure-tight seal around the molten pool of the weld.

The second is the type caused by presence of some resistance-raising substance on the surface through which the current passes which produces an extremely high temperature in a comparatively limited area of the weld, resulting in the actual local vaporization and explosion of the metal at that point. This tendency to form a local surface hot spot is again more pronounced when the general rate of temperature rise in the weld is very high since the difference in temperature between the local hot spot and the rest of the weld has less time to equalize than when the rate of temperature rise in the weld is comparatively slow. This same reasoning applies to the external flashes which are again largely caused by presence of some local resistance raiser which tends to increase the temperature of one particular spot on the surface very much above the surrounding temperature.

The use of preheat current appears to further minimize the tendency to spit or flash, by its apparent tendency to reduce or at least equalize to some extent the surface resistance of aluminum alloys.

The best remedy for the flashes, of course, lies in improvement of surface preparation.

(*m*) *Distortion.*—Distortion due to welding is usually caused either by the shrinkage effect of the weld material or by the release of the locked stresses normally present in most sheets due to an appreciable heating of the sheets during welding.

The first type can be overcome to some extent by making the welds in a certain staggered sequence placing consecutive welds as far apart on the joint as is practical, and by proper jigging to oppose the greatest possible stiffness force to the individual pull of each spot weld. To a certain extent it can be minimized by increasing the weld spacing and decreasing the volume of the weld. It can be corrected at the completion of the welding operation by stretching the metal in or around the welds to relieve the stress locked in the welds. Whenever possible this stretching is best accomplished by rolling the joint between steel rolls wide enough to span the rows constituting the joint and exerting 1000–1500 lb. pressure.

The second type of distortion, caused by excessive heating of the parts during welding, can be overcome by increasing the rate of temperature rise inside the weld and thus decreasing the heat absorbed by the parts being welded. Elimination of preheat current and increasing the rate of current rise will be of material assistance. It can also be minimized to some extent by proper staggering operation and by decreasing of the rate of welding.

Another common source of distortion is excessive deflection of the welding electrodes. When the electrodes come together on the sheet, lateral motion of the electrodes which would normally result from deflection of the electrode arms or from play in the pressure mechanism is resisted by friction between the sheets and the electrodes. However, when the weld is made the molten weld metal does not offer sufficient frictional forces to hold the sheets together against lateral motion and usually one of the sheets will slide over the other one and will be welded in the distorted position. Obviously the extent of sliding of the sheet is limited only by the amount of the deflection of the electrode and in case of parts already joined together by the stiffness of the sheet span between the weld being made and the nearest point of attachment. With extensive electrode deflection this form of distortion can be severe.

The type of distortion due to deflection of the welding electrodes can be minimized to a great extent by equalizing the amount of lateral motion of the electrodes by improving the stiffness of the electrode holders and by decreasing in general the play in the electrode arms and their deflection. It can also be minimized by rigid jigging of the parts and by adapting a weld sequence which will distribute the distortion uniformly over the whole part welded.

Section IV—Methods of Testing

1. *General*

The purpose of standard spot weld tests is determination, quantitative or qualitative, depending on the type of test, of the physical properties of spot welds.

The properties of spot welds which can be determined by standard tests are as follows:

(*a*) Structural strength.
(*b*) Structural strength consistency.
(*c*) Weld penetration.
(*d*) Weld metal structure.
(*e*) Depth of spot weld indentation.
(*f*) Surface separation.

The following tests are intended and shall be used for the determination of the above properties.

2. *Shear Pull Test*

The structural strength of a spot weld shall be determined by the Shear Pull Test.

This test shall consist of pulling in tension to destruction on a suitable testing machine of three test specimens, each test specimen obtained by lapping two or more strips of metal and joining them by a single spot weld.

In case of welds made between three- or four-ply gauge combinations, the strength of the bond between each two adjacent strips shall be tested in tension by pulling the adjacent strips to destruction, the complete test requiring the pulling of three specimens for every adjacent gauge combination present in the joint.

The ultimate strength of specimen, the diameter of the weld slug and the manner of failure, whether by shear of the weld metal or by tear of the parent metal around the weld, shall be recorded.

The record of the specimen shall include a description of the properties of the metal such as gauge thickness, the type of alloy and its tensile condition, that is, in the case of aluminum alloys, whether annealed or hardened to a certain degree or temper. The degree of hardness or of temper shall be recorded by measuring and recording the surface hardness of the specimen, of non-alclad alloys and by conducting a tensile test of the alclad specimens.

The dimensions of the specimen strips shall be as given on Fig. 22.

The amount of overlap shall be equal to width of the specimen in all cases.

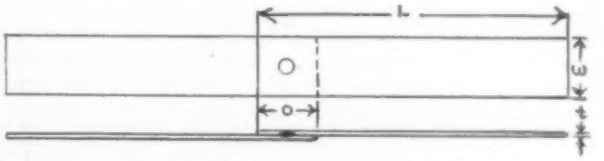
The specimen shall be prepared in such fashion as to insure the placement of the weld in the center of the overlap and with the longitudinal axes of the strips in good alignment.

The effect of eccentricity with the use of the above specimens can be disregarded in gauges up to 0.045 in. thick. In gauges above 0.045 in. thick provisions should be made to offset the grips by the distance between the center lines of the metal thicknesses gripped.

In case of combinations of unequal thicknesses, the dimension of the thicker strip may be reduced to the dimensions of the thinner of the two strips.

In case of specimens of three-ply combination or more of unequal thicknesses, the width of the strips used shall not be less than given in Fig. 22 except that the width of the thickest strip may be reduced to the width of the next thickest strip. Thus in case of a three-ply combination shown on Fig. 23, the width of the 0.064 strip may be reduced to the width of the 0.040 strip.

The length of the adjacent strips to be pulled in the three or more ply specimens shall not be less than given in Fig. 22 unless they are of unequal thickness when the length of the thickest piece may be reduced to that of the



Metal Thickness, In. *t*	Minimum Width, In. *w*	Minimum Length, In. *L*
0–0.031	5/8	3
0.031–0.045	3/4	4
0.046–0.059	1	4
0.060–0.070	1 1/4	5
0.071–0.100	1 1/2	5
Above 0.100	2	6
	O = w	

Fig. 22—Dimensions of Shear Pull Test Specimens

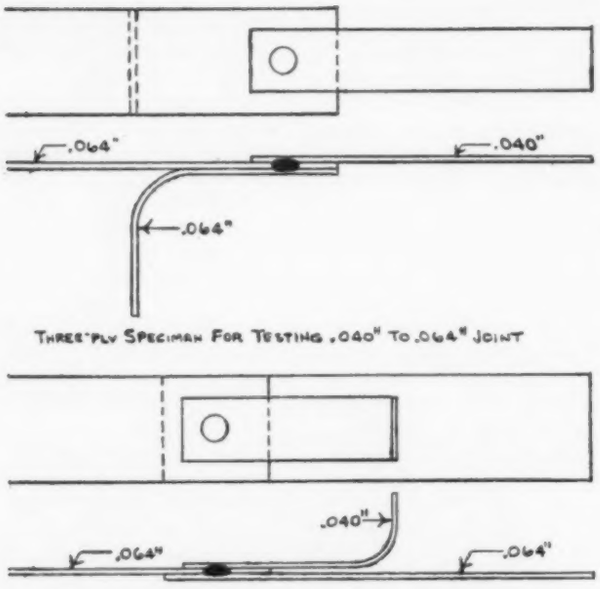


Fig. 23—Three-Ply Specimens for Shear Pull Test

thinnest. However, the lengths of the strips other than the ones being pulled must be reduced sufficiently to permit unobstructed gripping of the strips being pulled but not less than their widths, as given in Fig. 22.

The standard shear pull test shall consist of pulling to destruction of three test specimens for every joint combination tested. The average of the three specimens shall be considered as the result of the test, provided that the difference between the strength of each specimen and the average of the three is not over ±10% of the average. In cases where the strength of any one specimen is more or less than 10% of the average, this average shall not be considered as indicative of the strengths of the welds tested, and the test shall be considered as invalid.

3. Strength Consistency Test

The consistency of structural strength of spot welds shall be determined by the Strength Consistency Test. This test shall consist in pulling in tension to destruction on a suitable testing machine 25 test specimens obtained by lapping two pieces of metal, joining them by a single row of 25 spot welds placed side by side at a predetermined spacing and then cutting the joined pieces into 25 equal parts at right angles to the row of spot welds.

It is recommended that the cutting of the panels of 0.30 in. thick and heavier material into individual test specimens be done by means of a band saw or any other suitable sawing process rather than by means of a square shear or similar shearing operation since the shearing operation may damage the weld and in extreme cases actually reduce its strength before any test is conducted.

The dimensions of the joined pieces and the spacing of spot welds shall be such as to produce 25 specimens identical in all respects to the specimens used in shear pull test. (See Fig. 24.)

In case of three or four ply joints only the weld between one outside strip and an inside strip need be tested.

The test of the individual shear pull specimens shall be conducted in the same manner as in case of Shear Pull Test described in the preceding section.

The average strength of the 25 single spot specimens, that is, the value obtained by adding together the strengths of all specimens and dividing the result by 25, shall be considered as the average strength of the test. The difference between this average strength and the individual strength of a single spot specimen, divided by the average strength and multiplied by 100 shall be considered as the percentage deviation of that particular spot weld from the average of the test. The four spot welds exhibiting the greatest percentage deviation shall be considered in a group by themselves irrespective of their order during welding. The two welds giving, respectively, the greatest + and − % deviation shall be considered as representative of this group. The remaining 21 welds shall be considered as another group and the two spot welds of this group exhibiting, respectively, the greatest + and − % deviation shall be considered as representative of this group.

4. Weld Consistency Check Test

This test shall not be regarded as a substitute for the Strength Consistency Test, nor shall its results be considered as equivalent to the results of that test.

This test shall be regarded as a method of approximate determination of the general consistency of the welding process, to be used primarily for detection of serious flaws or variations in that process.

This test shall consist of pulling apart of 15 spot welds with the destructive force applied at one end of the specimen containing the welds at right angles to the plane of the weld and transmitted successively from one weld to another by the failure of the preceding weld, as shown on Fig. 26. The specimen thus tested shall consist of two or more strips of metal lapped together and joined by 15 spot welds placed approximately along the longitudinal center of the strips and spaced approximately in accordance with the fabricator's requirements for the particular gauge combination used. It is recommended that the width of the specimen be the same as the minimum width required of the shear pull specimen, but narrower width may be used if desired for purpose of economy provided that the strength of the strip is sufficient to produce

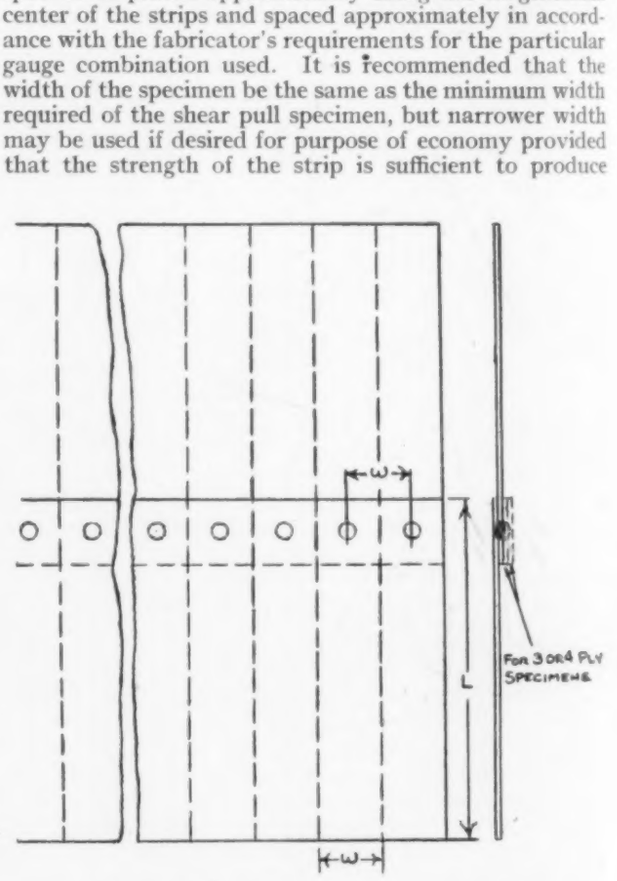
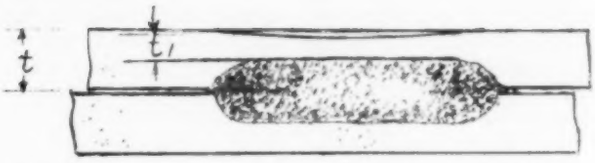
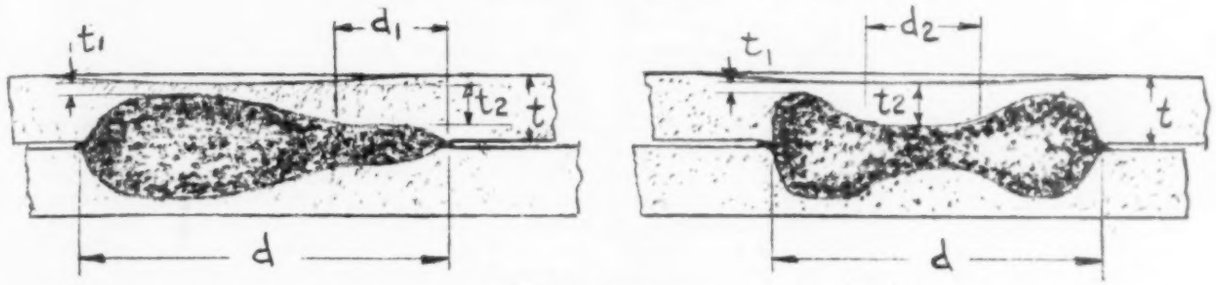


Fig. 24—Strength Consistency Test Specimen
For dimensions *L* and *w* see Fig. 22.



Case 1. Symmetrical welds. % Penetration = $\frac{t - t_1}{t}$ 100



Case 2. Irregular welds. % Max. penetration = $\frac{t - t_1}{t}$ 100. % Min. penetration = $\frac{t - t_2}{t}$ 100. To be considered only if d_1 or $d > 0.20d$.

Fig. 25—Weld Penetration Test

failure around or through the weld rather than across the strip.

After the destruction of the welds, the diameter of each weld button should be measured with a micrometer and a record made of all button diameters deviating more than the permitted amount from the average diameter of all buttons. In case of welds which failed by the failure of weld metal through the plane of the weld rather than through the parent metal around the periphery of the weld, the diameter of the weld casting shall be recorded.

5. Weld Penetration Test

This test shall consist of a visual examination of a cross-sectioned specimen obtained by lapping two strips of metal and joining them by a single spot weld through the center of the strips. The dimension of the original specimen in any one direction in the plane of the joint shall not be less than the width dimension of the specimen for the Shear Pull Test as given in Fig. 22.

The specimen after welding shall be cross-sectioned at right angles to the plane of the joint in such manner as to show on the half of the weld to be examined a section as nearly through the center of the weld as is practically possible. The sectioning operation and the preparation of the specimen for visual examination shall be conducted by any suitable means which will result in a finished surface sufficiently fine to permit observation of the line of demarcation between the cast structure of the weld and the wrought structure of the parent metal when subjected to suitable etch. However, the following procedure is recommended. Scribe a line on the surface of the weld bisecting the weld indentation. Rough cut with hack saw or do-all saw well outside the scribed line. Bring to size on a mill file, preferably by moving the specimen over the stationary file. Remove file marks by passing lightly over medium or fine grade of emery cloth.

Any suitable etching medium may be used, but the following is recommended:

Aluminum Alloy	Etching Medium
24S, 17S, 61S	Standard Keller's Etch (1% HF, 1.5% HCl, 2.5% H_2NO_3, 95% H_2O)
52S, 53S, 2S, 3S	½% HF Acid Solution

The penetration of the cast weld metal into the parent metal shall be measured with a decimal ruler marked in 0.010 or 0.020 of an inch or by means of a graduated low-power microscope in case of doubt.

The % ratio of the dimension obtained by subtracting the distance between the outside surface of the sheet and the beginning of the cast weld metal from the total thickness of the sheet, to the total thickness of the sheet shall be considered as the percentage of penetration of the weld into that sheet, as illustrated in Fig. 25. In case of dumbbell or irregularly shaped welds, both the maximum and minimum penetration shall be measured as illustrated in Fig. 25 and considered as applicable to the weld in determining the weld quality.

6. Weld Metal Structure Test

This test shall be substantially the same as the Weld Penetration Test with the following exceptions. The

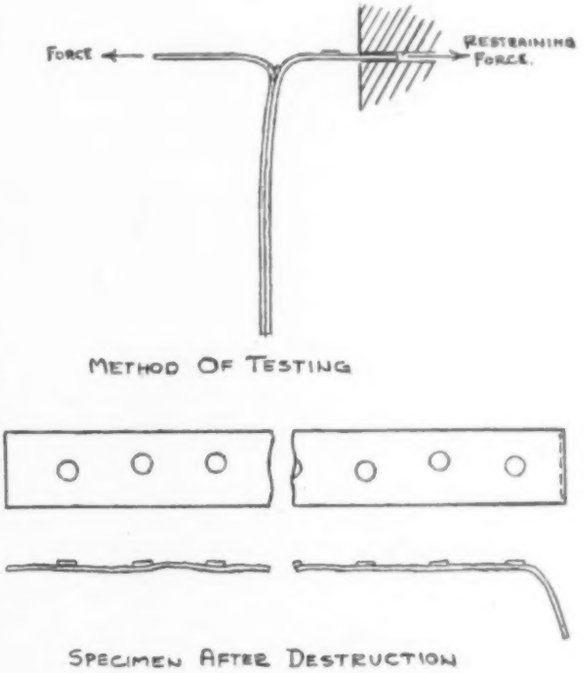


Fig. 26—Weld Consistency Check Test Specimen

length of the pieces lapped shall be such as to permit placement of three spot welds at the same spacing as prescribed in production for the gauges and parts joined. After sectioning, the three specimens shall be mounted by suitable means in lucite or equivalent supporting medium and shall be polished to a degree suitable for micrographic examination.

The polishing and etching technique shall be in accordance with the latest recommendations of the Aluminum Company of America for the particular alloy used and shall be such as to clearly show all voids, cavities and cracks in the structure of the weld. For detailed instructions in the technique of polishing and etching of cross-sectioned spot welds see N.A.C.A. Report No. 6 of the Spot Welding Investigation at Rensselaer Polytechnic Institute. It is recommended that the method and technique described in this report be followed.

The visual examination of the finished specimen shall be conducted by means of a suitable microscope capable of not less than ×20 magnification. The shape and size of the weld structure, the presence of all defects and the size of all severe cracks and cavities as well as the extent or severity of the heat-treated zone shall be recorded.

7. Weld Indentation Test

This test shall consist in examining by means of a suitable surface dial gauge the depth of indentation caused by spot welds of a test specimen obtained by lapping two strips of metal and joining them by three spot welds. The dimensions of the specimen and the weld spacing shall be the same as in case of Weld Metal Structure Test Specimen.

For the determination of the depth of the weld indentation, the specimen shall be bolted down to a suitable surface plate and the contour of the weld surface explored with a suitable surface dial gauge. The depth of indentation of a spot weld shall be considered as the difference between the lowest point on the surface of the weld indentation that can be measured with the dial gauge and the surface of parent metal immediately adjacent to the surface of the weld.

Section V—Inspection

1. Purpose

The purpose of inspection of spot welding in aircraft is to insure good quality of welding during production and on the finished product.

Standards of inspection shall be such as to give positive assurance both to the designer and the ultimate user of aircraft that the welding present on aircraft is in accordance with the prescribed standards of quality and that all welding produced by the fabricator which for some reason may not meet with these standards is either rejected or salvaged by suitable repairs.

The purpose of this section is to provide a standard method for inspection of welding during production and to recommend certain inspection procedures and practices facilitating both inspection and production.

2. Inspection Personnel

Since a great deal of spot welding inspection must be visual a high degree of skill and experience is required from an inspector if he is to exercise his job with efficiency and dispatch. For this reason it is recommended that inspection of spot-welded assemblies and spot weld production be made a full-time job and that the inspector or inspectors assigned to this task have no other duties. This will permit the inspector or inspectors to continually improve their knowledge of welding processes and quality and will materially reduce the delay in production due to inspection.

The execution of routine tests prescribed by inspection standards imposes considerable duties on the welding inspector irrespective of the quality of the welding produced by the equipment for which he is responsible. It is desirable that his assignment is such that his time is not fully occupied in conducting routine tests, but that he may have considerable time free from routine duties, during which he should be free to observe the operation of the equipment, its personnel, and the general functioning of the welding department and assist the operator or supervisor in advisory capacity at the first sign of incipient trouble.

An inspector should have excellent eyesight and he should be thoroughly familiar with the Standards of spot welding requirements as established by his own company, by the users of aircraft and by these Standards and Recommended Practices.

He should have had preferably some actual experience in shop welding practices and fabrication. It is desirable that he should have some technical education and should have at least a fundamental understanding of the principles involved in spot welding of aluminum alloys. He should be thoroughly familiar with the operation of the welding equipment, for the quality of the output of which he is responsible and he should be capable, if necessary, to point out to the operator or the welding supervisor such obvious mistakes as an inexperienced or poorly trained operator may be expected to commit.

An inspector should be thoroughly familiar with the principles governing the relationship between the welding technique and the resultant quality of the welds and he should also be familiar with the system of welding schedules as used by the production department, though his responsibility should not extend to the enforcement of the use of the proper schedule by the operator.

An inspector's mentality should be such that he should regard himself and his job as one where the ultimate quality of the product can be best secured by his cheerful and helpful cooperation with the entire production department personnel and his capacity for constructive rather than destructive criticism, and that consistent failure of the production department to produce results satisfactory to him may be a reflection on his own ability as well as on factors beyond his control.

It is, of course, needless to state that the spot welding inspector shall be responsible only to the proper inspection department of the plant and not to the welding supervisor or welding engineer.

3. Duties of Inspector

One of the first duties of the inspector is to satisfy himself with the operation of the spot welding equipment. His interest in the operation of the equipment, however, should not extend beyond checking the results as produced by the equipment though his knowledge of the process should make him helpful in criticizing or suggesting any changes in the actual operation of the equipment itself.

It shall be the responsibility of the spot welding inspector to see that every piece of new welding apparatus has been properly qualified for the job for which it is intended, by conducting proper machine qualification tests, as soon as the apparatus is ready for production.

It shall also be the duty of the inspector to satisfy himself that the surface preparation process is functioning satisfactorily and that proper inspection of this process

is conducted by the personnel assigned to this task, and to draw attention of the welding supervisor and the welding engineer if he believes variations exist in the operation of this process, affecting the quality of the welding.

It shall be the duty of the inspector to familiarize himself with the drawings of the parts to be welded beforehand in order that he may be thoroughly familiar with the purpose and the function of the welding used in joining these parts. Although the matter of welding design is not part of the inspector's responsibility he should draw to the attention of the welding engineer or of his superiors any details of design which, based on his knowledge and experience, would tend to make welding of good quality impossible or difficult in production.

It shall also be the duty of the inspector to assure himself that the parts are joined by welding in accordance with the intent of the assembly drawings, including the fit and location of component parts, and the number, position and spacing of welds.

The two primary duties of a spot welding inspector shall be in assuring himself that the spot welding equipment and operator are continually producing welding of good quality and in inspecting the finished product to assure himself as far as such inspection permits, that it contains no defective welding which might have passed unnoticed by him in production.

Although these two duties are sometimes divided between different inspectors it is strongly recommended that they be combined in one man and, furthermore, that the inspection of the finished parts or assemblies be conducted as soon after their completion as possible in order that any trend to defective welding as evidenced on the completed part may be discovered and checked at the earliest possible time.

It shall also be the duty of the inspector to observe, as much as is compatible with the execution of his primary duties, the production of welding under his charge in order to help prevent the operation of all equipment which is producing welding obviously defective to a visual observation, even though the production of such welding is not his responsibility.

Further duties of the inspector shall be to keep complete records of all tests conducted by him in the course of his duties, to stamp inspected parts with his personal stamp if satisfactory, to keep complete records of all unsatisfactory finished parts and to cooperate with the production and engineering departments in the salvage of the rejected parts whenever possible.

4. Standards of Inspection

In general, the standards of inspection shall be such as to insure that all welding shall be of good quality as defined in Section I of these Standards. More specifically, the following shall be followed.

(*a*) *Qualification of New Equipment.*—Before any welding equipment of a make, type or rating different from the welding equipment already in service is placed in operation on any customer's work, the spot welding inspector shall conduct the following tests.

1. Shear Pull Test, for every metal and every gauge combination that the machine is intended to weld in production.
2. Strength Consistency Test, for every metal and in the following gauge combinations that the machine is intended to weld in production:
   Thinnest gauge to thinnest gauge
   Thickest gauge to thickest gauge
   Thinnest gauge to thickest gauge
3. Weld Metal Structure Test for every metal and gauge combination that the machine is intended to weld in production.

These tests shall be made with the welding schedules established for the machine by the welding engineer and on material with its surface prepared by the identical surface preparation method as the parts the machine is intended to weld in production.

The results of the test shall be such as to prove the machine capable of producing good welding as defined under Section I of these Standards.

If the machine successfully passes the tests for some materials or gauge combinations, but not for the others it shall be considered as qualified for production welding of those material or gauge combinations only and provided that all three types of tests were satisfactory.

Under no conditions shall the inspector qualify the machine for production welding of metals or gauge combinations other than those which were successfully tested, except in the case of gauge combinations which lie within the range of combinations successfully tested.

(*b*) *Set-up Inspection.*—Before allowing welding of any new or different parts or of any welding necessitating the use of a different welding schedule than the one on which the machine was operating, the inspector shall conduct the following tests.

1. Shear Pull Test, on the metal and gauge combination identical to the one which it is proposed to weld.
2. Weld Penetration Test, on the metal and gauge combination identical to the one which it is proposed to weld.

The results of the tests shall indicate welding of good quality as defined in Section I of these Standards. The results of the Shear Pull Test shall also indicate weld strength equal to or in excess of the fabricator's strength requirement applicable to the part or assembly it is proposed to weld, if the fabricator has established such strength requirement and if it is higher than the minimum value for good welding required by these Standards.

Should the proposed set-up fail to pass the above tests, the inspector shall first satisfy himself that the operator is using the proper welding schedule prescribed for the operation, and if that is the case shall summon the welding supervisor and direct his attention to the failure of the set-up to pass the required inspection. The operation then shall not commence until the conditions which caused the failure have been rectified and until the machine passes successfully another set-up inspection which in this case shall be augmented by the inspector also conducting a Standard Weld Consistency Check Test.

(*c*) *Production Quality Inspection.*—The inspector shall assure himself that the quality of welding during production is the same as at the set-up inspection, by conducting, at least every two hours, a Standard Shear Pull Test for every machine assigned to him.

The results of these tests shall at all times be in accordance with the Standards of good welding as given in Section I and, in addition, the deviation in the shear strength of any one specimen pulled during these tests shall not be greater than $\pm 20\%$ of the average of all the test specimens tested during the Production Quality Inspection and since the Set-up Inspection. The results of the Set-up Inspection Shear Pull Test shall be included in the average considered.

As soon as a deviation of over $\pm 20\%$ appears during production inspection, the inspector shall conduct a Weld Consistency Check Test. If the results shown by this test are in accordance with the Standards of good quality as defined in Section I, the inspector shall permit continuation of the operation. If not, the operation shall be suspended and renewed only after proper corrections

in the welding process have been made to enable it to pass the Shear Pull, Weld Penetration and Weld Consistency Check Tests.

(*d*) *Additional Production Inspection.*—In both the set-up and production inspections it shall be part of the inspector's duties to satisfy himself that the strips provided for Shear Pull Test have the same physical properties as the parts welded, such as gauge thickness, chemical composition and ultimate strength, are cold worked or heat treated to the same hardness as the parts welded, and have received the same surface preparation as the parts welded.

He shall furthermore satisfy himself to the best of his ability that the Standard Shear Pull Test as conducted by him is characteristic of the welding conducted on the finished part. In case of some parts it is possible to utilize a portion of the part neither visible from the outside nor structurally important on which one or two welds may be made and tested to destruction by twisting or prying the parts apart without in any way damaging the usefulness of the parts. In such cases the inspector should do this at each set-up and production test. Whenever this is impractical, the inspector should test the second or third weld made on the part welded after the set-up and production tests by means of a thin steel knife not over 0.020 in. thick inserted between the lapped parts alongside the weld in such fashion as to exert a direct tension force upon the edge of the weld, taking care that at no time should the force exerted by him be sufficient to cause appreciable plastic deformation of the metal alongside the spot weld. In all conditions the weld should be capable of sustaining such loading without fracturing.

(*e*) *Inspection of Finished Parts.*—It shall be the duty of the spot welding inspector to inspect visually every spot weld on every part or assembly for which he is responsible and to assure himself that their general quality is good as defined in Section I of these Standards. In addition to this he shall assure himself that the welds exhibit sufficient structural strength to withstand such loadings as may be applied to the part or assembly manually by bending or twisting the part without exceeding the elastic limit of any section of the part or assembly. In case of doubt he should also test occasional welds by the pry method described in the preceding section (*d*).

5. *Disposition of Unsatisfactory Welding*

The disposition of parts or assemblies containing welding whose general quality does not meet the requirements prescribed for good welding in these Standards shall be in accordance with the procedure established by the individual fabricator for this purpose. Since such disposition is influenced to a very large extent by the service for which the parts or assemblies are intended as well as by the type of defect, it is impossible to prescribe any general procedure for disposition of parts joined by unsatisfactory welding.

Only general suggestions and recommendations can be given.

Thus excessive indentation on surfaces exposed to air stream may be usually corrected by proper cold working of the welds unless the nature of the assembly or part is such as to render such cold work impractical or ineffective in which case the disposition of the part may have to be determined by a mutual agreement of the customer and the fabricator.

The presence of welds with cracks extending to the surface of material or of welds exhibiting excessive quantity of flashes or spits, beyond the tolerances permitted for good welding can be corrected either by placement of welds alongside each defective weld or by drilling out the defective welds and replacing them with suitable rivets—or the part may be scrapped. The exact procedure in this case should again be a matter for the individual fabricator to determine, depending on his particular conditions and the type of aircraft or part he is manufacturing, though these defects, in general, should not occur on a finished part very often as their occurrence would be normally detected while the part is being welded and should be corrected before sufficient number of welds with this defect can be placed on the part to condemn the general quality of the welding on the part.

All parts exhibiting structurally weak welds of very low or zero strength, should be rewelded, preferably by placing new welds between the original welds.

Section VI—Design

1. *General*

Spot welding, when considered from the point of view of design, is merely one of the many structural elements at the disposal of the designer, and which can be used by him in a great variety of ways, depending both upon the purpose of structure and on his particular theory of design. It would be obviously presumptuous to attempt to dictate or even to advocate here any one type or method of design as superior to others.

There are, however, two aspects of spot-welded design which should be presented to the structural engineer to assist him in a better understanding of the peculiarities of spot welding as a method of joining.

The first aspect is that of the physical properties of spot-welded joints. A structural designer has a right to know and can rightfully demand the unit strengths which can be expected from a joint made by any one process when subjected to various types of static and dynamic stress. In case of a method of joining such as spot welding, which is composed of a number of individual points of attachment, he has a further right to expect a knowledge of the best or the most efficient pattern or combination of individual points of attachment for the desired strength of the joint.

It is unfortunate, however, that this aspect of spot welding is still in the course of development and very little, in the way of definitely established facts, is now available. Accordingly, only the barest essentials of this subject can be presented at this time.

The second aspect of the spot-welded design is based primarily on the fact that the chief advantage of spot welding as a structural element is its comparative ease and rapidity of production. This characteristic, however, is contingent upon adherence to certain simple rules of design, the word design here applying primarily to the details of the joint used. Thus, as will be seen later, a comparatively minor difference in the detail of a joint may spell the difference between making the joint essentially easy and suitable for spot welding or extremely difficult and expensive. This second aspect of spot-welded design deals then primarily with furnishing the structural designer with the facts regarding the scope and limitations of spot welding in so far as its ability to join rapidly and cheaply is concerned.

2. *Structural Properties of Spot-Welded Joints*

As stated above, reliable information on this subject is sadly lacking at this time although it is hoped that various investigations now under way, will produce positive results in the near future.

A spot weld develops its fullest strength when sub-

Table 10—Theoretical Weld Spacing Necessary for 100% Efficient Joint

(All dimensions in inches)

24ST Alclad Alloy

Gauge	Lb. per In. Parent Metal	Theoretical No. of Spot Welds per In. Required for 100% Efficient Joint*	Theoretical Spacing, 1 Row	Theoretical Spacing, 2 Rows
0.016	1000	7.15	0.140	0.280
0.020	1240	7.10	0.141	0.282
0.025	1550	6.60	0.151	0.302
0.032	1985	6.20	0.161	0.322
0.040	2480	5.80	0.172	0.344
0.045	2790	5.60	0.178	0.356
0.051	3160	5.25	0.190	0.380
0.064	3970	4.40	0.227	0.454
0.072	4460	4.25	0.235	0.470
0.081	5020	3.70	0.270	0.540

* At minimum strength spot welds as shown in Fig. 3.

jected to shear load. The individual limits of the shear load which a good spot weld can carry are given in Fig. 3, and the designer can demand any reasonable strength from a spot weld within these limits. However, the welding technique and process required to produce spot welds of different strength, even when they lie within the limits of good spot welds, may vary considerably and thus it is generally impractical to call, in any one organization, for more than one or possibly two minimum strength requirements for any one gauge combination, irrespective of the structure considered.

In establishing a definite minimum shear strength requirement, a designer must bear in mind that the strongest individual spot weld does not necessarily produce the strongest joint, and, therefore, to merely demand the strongest individual spot weld without correlating that requirement with a definite spot weld pattern is often pointless.

Whenever spot welds are used for joining two parts which are subsequently stressed in such manner as to place the joint in tension and the individual spot welds in shear, as would be, for instance, true in case of spliced wing skins, the objective usually is to secure a joint whose ultimate strength is equal to or superior to the parent metal. Because of the change from a heat-treated wrought structure to an annealed cast structure, the spot welds on most aluminum alloys are rather weak when compared to the strength of the parent metal. Table 10 gives an idea of the number of spot welds required to produce a joint theoretically 100% efficient.* It will be noted that even when spot welds are placed in a double staggered row, the required spacing between the welds is still below the practical minimum which can be maintained in production. The strength of individual spot welds considered in this case was that of the lower limit spot welds as given in Fig. 3. Stronger individual spot welds may permit the use of wider spacing. However, stronger individual spot welds may weaken sheet efficiency, that is, may weaken the sheet itself when subjected to tension loading parallel to the line of joint and, therefore, may introduce other complications.

As already stated, the optimum spot weld size and pattern has not as yet been conclusively determined and, therefore, no recommendation on this subject can be made now. It is clear, however, from analysis of Table 10 that in cases where maximum strength is required in a lap joint, two or more rows of spot welds are required.

In a great many cases, the spot welds are called upon to join stiffening members such as channels, angles or hat sections to panels or skins, in which cases the spacing or pattern of welds is primarily a function of the unit stress which the panel is intended to carry and not of the individual strength of the welds. Experience indicates that with good spot welds failure of such stiffened panels occurs through the buckling of the skin between the welds, although sometimes after the failure, and in case of severe permanent buckling, individual spot welds may fail adjacent to the buckle.

The spacing of spot welds then in these stiffener panel combinations is subject to the same rules as the spacing of rivets, and can be obtained from various empirical curves such as, for instance, in Fig. 10-30 of Volume I of *Airplane Structures* by Niles and Newell. It has been customary, however, in case of some airplane manufacturers, to decrease that spacing in case of spot welds by multiplying the rivet spacing by factors 0.75 or 0.666. There is no indication, however, that this is necessary, except perhaps as a precautionary measure to compensate for possible poor welding.

An important aspect of the structural properties of spot welds is their effect on the tensile strength of the sheet or sheets containing the welds. This aspect bears close analogy to the effect of rivet holes on the tensile properties of the sheet. In this case it is obvious that the tensile strength of the sheet decreases rapidly as the number of holes and the dimensions of the holes are increased. The sheet efficiency in this case is the percentage ratio of the strength of the sheet containing holes to virgin sheet.

In case of spot welds the definition of the sheet efficiency is the same, that is, the tensile strength of the sheet containing a row of spot welds to the sheet without them. However, in case of spot welds it is impractical to consider a single sheet containing, as it may, one-half of a spot weld and for this reason tests of sheet efficiency must be conducted by testing in tension two sheets or two strips joined by one or more spot welds.

Few data are now available regarding the sheet efficiency of spot-welded structures. In general it appears that the presence of a spot weld, though in no way comparable to that of a rivet hole, nevertheless tends to reduce the tensile strength of the sheet or sheets containing the weld.

3. Minimum Practical Spot Weld Spacing, Edge Distance and Clearance

The formation of a spot weld requires smooth metal

Table 11—A Method of Determining Minimum Weld Spacing

(All dimensions in inches)

Gauge	Max. Weld Diameter*	Max. Surface Indentation	Min. Practical Weld Spacing	Min. Distance Between Rows
0.016	0.14	0.20	0.32 or 5/16	1/4
0.020	0.15	0.22	0.34 or 3/8	1/4
0.032	0.175	0.27	0.40 or 3/8	5/16
0.040	0.20	0.29	0.42 or 7/16	5/16
0.045	0.22	0.32	0.45 or 7/16	5/16
0.051	0.24	0.34	0.47 or 1/2	3/8
0.064	0.28	0.38	0.52 or 1/2	3/8
0.072	0.32	0.42	0.56 or 9/16	7/16
0.081	0.35	0.46	0.62 or 5/8	1/2
0.093	0.37	0.48	0.65 or 5/8	1/2
0.102	0.39	0.50	0.68 or 5/8	1/2
0.125	0.41	0.52	0.71 or 3/4	5/8

* Based on Fig. 3.

* Theoretical strength of a joint containing n welds of s lbs. each would be ns lbs. In actual practice, however, because of the stress concentration, and uneven load distribution between spots, the strength of the joint is invariably less and is given by the expression $knsi$, where k is always less than unity and varies inversely with both n and s.

Factor k is also dependent on the weld pattern and even under the most favorable conditions seldom exceeds 0.90.

Table 12—Weld Spacing Specified in Industry

(All dimensions in inches)

	.016	.020	.025	.032	.040	.045	.051	.064	.072	.081	.091	.102	.125
Bell													
2 rows	.442	.530	.707	.707	.885	.885	.885	1.06	1.06	1.41	1.6		
Distance between rows	.221	.265	.354	.354	.443	.443	.443	.53	.53	.71	.8		
Boeing	.38	.38	.50	.50	.62	.62	.75			.88	.88		
Consolidated													
Double Row	.5	.5	.75	.75	.75	.75	1.0	1.0	1.0	1.0	1.0	1-1/4	1-1/4
Distance between Rows	.25	.25	.31	.31	.38	.38	.50	.50	.56	.56	.56	.63	.63
Curtiss													
2 Rows		.437	.437	.500	.500	.562	.562	.625	.625	.625	.75		
Distance between Rows		.38	.38	.433	.433	.487	.487	.541	.541	.541	.65		
Douglas													
Single Row (R.)	.5	.75.	.75	1	1	1	1	1-1/4	1-1/4	1-1/2			
M.	.25	.25	.25	.31	.38	.38	.5	.63	.63	.88			
Lockheed													
Single or Double Row (Std.)	.5	.5	.63	.75	1.0	1.0	1.0	1-1/4	1-1/4	1-1/4	1-1/4	1-1/4	1-1/4
Single Row or Double Row (Min.)	.38	.38	.5	.5	.63	.63	.75	.88	.88	.88	1.0	1.0	1.0
Distance between rows = spacing x $\sqrt{2}$													
Vought-Sikorsky	Primary Structures (Sec. Structures, spacing for all gauges is 5/8" for 1 row and 1" for 2.												
Single Row	.500	.500	.500	.500	.500	.500	.625	.625	.625	.625	.625		
Double Row	.750	.750	.750	.750	.750	.750	1.00	1.00	1.00	1.00	1.00		
Distance between Rows	.625	.625	.625	.625	.625	.625	.625	.625	.625	.625	.625		

surface, and consequently production of overlapping spot welds is not at present practical unless the spot welds are produced by means of electrodes in continual contact with the metal being welded as, for instance, in case of seam welding.

The absolute minimum spacing of spot welds would then be a spacing wherein each weld impression would be adjacent to the preceding weld impression, but not touching it. Under practical operating conditions, it is obviously impossible to space the welds with absolute accuracy, and a certain minimum clearance between weld impressions must be provided if occasional overlapping of spot welds is to be avoided. Assuming a clearance of $^1/_8$ in. to $^3/_{16}$ in., a table of minimum spot spacing can be prepared as shown in Table 11.

In addition to the above limiting factor, in some welding techniques, particularly the ones utilizing a very long thermal cycle and when used on comparatively heavy gauge combination, difficulty is encountered in appreciable decrease in the size of the spot welds due to short circuiting effect of the adjacent spot weld on the spot weld being made. With the majority of modern welding methods, however, the extent of this short circuiting or proximity effect has been considerably reduced. In general it can be completely disregarded for light gauges 0.040 and thinner and in case of low conductivity alloys such as 24ST and 17ST as well as 52S and 53S alloys this disregard can be extended to medium thickness gauges as well.

Table 12 gives the recommended and minimum permissible weld spacing as now specified by several aircraft companies.

It is recommended that the minimum spot weld spacing for average structural design is never less than given in Table 13. It must be remembered that the recommended minimum spacing represents the minimum spacing which can be accomplished under normal production conditions without sacrificing operating speed or efficiency. In extreme cases it is usually possible to produce closer spaced welds although this will entail considerable sacrifice of welding speed, and efficiency, and will, in the majority of cases, require special technique and handling, thus completely defeating the inherent advantages of spot welding.

If a spot weld is placed too close to the edge of a sheet, expansion and contraction forces present in a spot weld may force out or bulge the strip of parent metal separating the spot weld from the end of the sheet which in extreme cases may actually split open causing a crack extending from the spot weld radially toward the edge of the sheet. Such a spot weld is obviously considerably weaker and cannot be tolerated in any quantity. Accordingly, it becomes necessary to provide certain minimum distances between the center line of a spot weld and the edge of the sheet or part containing the spot weld.

Table 14 gives the minimum edge distances as specified by several aircraft companies.

It is recommended that for average structural design, the minimum edge distance between the center line of spot weld and the edge of the sheet be not less than specified in Table 13.

As in cases of weld spacing, smaller edge distances are possible and in extreme cases can be called for, subject to approval of the welding engineer. It will be found, however, that the presence of such smaller edge distances will so handicap production by reducing operating speed and requiring special welding technique and welding set-ups, as to defeat the inherent purpose of spot welding.

In any two or more lapped parts there will be two edges or ends of part or flange, one on each side of the

Table 13—Recommended Minimum Weld Spacing, Edge Distance, Clearance in Inches

(All dimensions in inches)

	0.016	0.020	0.025	0.032	0.040	0.045	0.051	0.064	0.072	0.081	0.091	0.102	0.125
Minimum edge distance	3/16	3/16	7/32	1/4	1/4	5/16	5/16	3/8	3/8	3/8	7/16	7/16	1/2
Minimum spot spacing	5/16	3/8	3/8	3/8	7/16	7/16	1/2	1/2	9/16	5/8	5/8	3/4	1
Minimum distance between rows of staggered welds	1/4	1/4	5/16	5/16	5/16	5/16	3/8	3/8	7/16	1/2	1/2	1/2	5/8
Minimum overlap, flange width or "flat" required	3/8	3/8	7/16	1/2	1/2	5/8	5/8	3/4	3/4	3/4	7/8	7/8	1
Minimum unobstructed area required to place a weld diameter	7/16	9/16	9/16	11/16	11/16	11/16	11/16	11/16	11/16	11/16	15/16	15/16	15/16

NOTE: In case of combinations of uneven thicknesses, the thickness of the next to the heaviest gauge joined is to be considered as the thickness governing the above dimensions.

spot weld parallel to the line of joint, and thus the minimum overlap of two sheets or parts joined or the minimum width of any flange or flat of any two parts joined will be twice the minimum edge distance as given in Table 13. Obviously, if more than one row of spot welds is made, this distance must be increased by the distance between the row of spot welds made.

In order to place a weld at any one point, this point must be accessible to a welding electrode which is of certain definite minimum dimensions, if good quality welding is to be obtained. There must be, accordingly, a minimum unobstructed area present around a point at which it is desired to make a weld. Table 15 gives the dimensions of the unobstructed areas for straight electrodes and Table 16 for offset electrodes, as practiced by several aircraft companies.

It is recommended that the dimensions of the unobstructed area around the point of attachment be not less than given in Table 13. Again it must be remembered that welds can be placed in areas with less unobstructed space but only at a usually prohibitive sacrifice of operating efficiency and weld quality.

An exception to the above recommendation can be made in case of long narrow grooves such as are present, for instance, between the corrugations of stiffening sections or alongside flanges on flat sections or channels where roller welding wheels would normally be used. In those cases, and only when roller welding equipment is available, dimension of the minimum unobstructed space at right angle to the axis of the corrugation or channel may be reduced to that of the minimum flat or flange distance as called for in Table 13.

A spot weld does not have to be placed necessarily in the exact center of the minimum clearance space required as special offset electrodes are entirely practical, provided the eccentricity of the spot is not great enough to cause the spot to lie closer to the edge of the joint than called for on the minimum edge distance table.

4. Design of Joints for Spot Welding

In designing joints for spot welding it must always be remembered that for maximum operating efficiency the vertical approach to the joint on either side must be unobstructed. In addition, a vertical wall in the neighborhood of the joint on either side of the joint is always desirable provided it is not over 12 in. in height as it can be made to serve as a guide for the welding electrode and thus facilitate the proper alignment of the welds. Figures 27 and 28 show good and bad types of joints in so far as spot welding is concerned.

5. Fit of Parts

It must be remembered that well-fitting parallel surfaces are essential if the advantages of spot welding are

Table 14—Minimum Edge Distance Specified in Industry

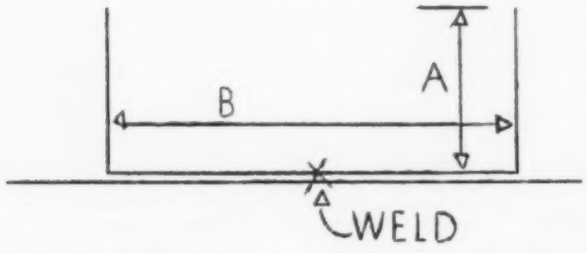
24ST Alclad

(All dimensions in inches)

	.016	.020	.025	.032	.040	.045	.051	.064	.072	.081	.091	.102	.125
Bell	3/16	3/16	1/4	1/4	5/16	5/16	5/16	3/8	3/8	3/8	7/16		
Boeing	1/4	1/4	1/4	5/16	5/16	5/16	3/8	3/8	7/16	7/16	7/16		
Consolidated	1/8	1/8	3/16	3/16	1/4	1/4	5/16	5/16		3/8	3/8	1/2	1/2
Curtiss		3/16	3/16	7/32	1/4	9/32	9/32	5/16	5/16	11/32	3/8		
Douglas Minimum	1/8	1/8	3/16	3/16	1/4	1/4	1/4	1/4	1/4	3/8			
Recommended	3/16	3/16	1/4	1/4	5/16	5/16	5/16	5/16	1/2				
Lockheed Minimum	3/16	3/16	7/32	7/32	1/4	1/4	5/16	5/16	3/8	3/8	7/16	7/16	1/2
Maximum	1/4	1/4	5/16	5/16	3/8	3/8	1/2	1/2	5/8	5/8	11/16	11/16	3/4
Vega Minimum	3/16	3/16	7/32	1/4	9/32	9/32	11/32	3/8	3/8	7/16	7/16	1/2	
Maximum	1/4	1/4	5/16	5/16	3/8	3/8	1/2	9/16	9/16	5/8	11/16	3/4	
Vought-Sikorsky	3/16	3/16	3/16	1/4	1/4	1/4	5/16	5/16	3/8	3/8	3/8	7/16	9/16

Table 15—Minimum Electrode Clearance Specified in Industry

Straight Electrode



	Vought-Sikorsky		Boeing		Lockheed	
Gauge	B (A < 2 In.)	B (A > 2 In.)	B (A < 1.5 In.)	B (A < 12 In.)	B (A < 2 In.)	B (A < 2 In.)
0.016	7/16	15/16	3/4	1 5/8	9/16	1 1/2
0.020	7/16	15/16	3/4	1 5/8	9/16	1 1/2
0.025	7/16	15/16	3/4	1 5/8	9/16	1 1/2
0.032	9/16	15/16	3/4	1 5/8	9/16	1 1/2
0.040	9/16	15/16	3/4	1 5/8	9/16	1 1/2
0.045	11/16	15/16	3/4	1 5/8	9/16	1 1/2
0.051	11/16	15/16	3/4	1 5/8	9/16	1 1/2
0.064	11/16	15/16	3/4	1 5/8	9/16	1 1/2
0.072	11/16	15/16	3/4	1 5/8	9/16	1 1/2
0.081	11/16	15/16	3/4	1 5/8	9/16	1 1/2
0.093	11/16	15/16	3/4	1 5/8	9/16	1 1/2
0.102	15/16	15/16	...	...	...	...
0.125	15/16	15/16	...	...	...	...

(All dimensions in inches)

to be fully realized. Accordingly, spot welding is at its best in joining flat stock or mass-produced, die-stamped parts.

Hand-formed or drop hammer formed parts usually require special care in spot welding since it is difficult to produce, by these processes, identical parts with flat, even surfaces of uniform thickness essential to good welding. It must be remembered that a difference in thickness of either sheet of as little as 10% may have an appreciable effect on the quality of the resultant weld, and, therefore, the processes like hand forming or drop hammering which frequently tend to stretch the metal to a varying extent are poorly suited to producing joints for spot welding. In addition, drop hammers, particularly when not properly kept, frequently imbed particles of zinc, tin or other die material, or dirt into the aluminum, making welding conditions extremely difficult.

Poorly fitted parts which have to be pulled together by the welding electrodes, in addition to slowing down operating conditions and tending to lower the quality of welding, are apt to produce spot welds with high residual stresses which sometimes require only a slight additional external load to fail.

All effort, therefore, must be made to insure good fit of parts in spot-welded structures.

6. *Gauge Combinations*

Welding of very thin to very heavy gauge combinations is not considered at present practical whenever the thin material is required to be smooth. Experience indicates that with present welding conditions a thick to thin ratio of 2 1/2:1 must be considered as maximum compatible with good welding although it is possible, under certain conditions, and usually by greatly sacrificing operating efficiency, to extend the ratio to 3:1.

There appears to be no limiting factor to the ratio of thick to thin combination which can be safely welded whenever the thin gauge can be made to take its share or the entire share of the weld indentation, that is, whenever a pointed or sharply domed electrode can be used against the thin section.

Spot welding of aluminum alloys at present is largely limited to not over three thicknesses, although under favorable conditions up to four thicknesses can be spot welded.

7. *Weldability of Different Alloys*

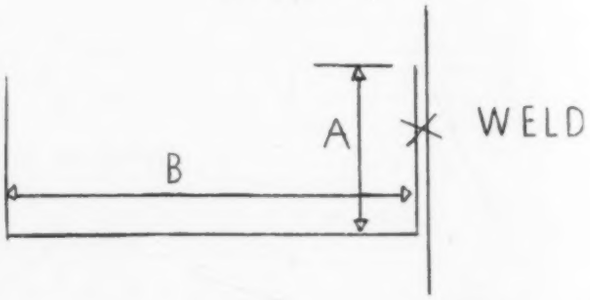
The welding characteristics of the various aluminum alloys vary considerably. In general, all can be spot welded although some combinations of different types are more difficult to spot weld than others. In addition, each type of alloy presents its own difficulties and, conversely, has some advantages which are summarized as follows:

In general, all high-tensile alloys are easier to weld in so far as they have less tendency for sheet separation and, in general, better weld strength consistency. On the other hand, the high-tensile alloys offer considerably more difficulty with the soundness of weld metal, that is, the tendency to cracks and porosity is greater than in low-tensile alloys. Conversely, low-tensile alloy welds offer considerable difficulty in so far as sheet separation, weld strength, consistency and surface indentation are concerned, but are generally free from cracks and porosity, even when made under the most adverse conditions.

In general, the aluminum clad alloys are more difficult to weld than the bare alloys in so far as the introduction of low resistance, high melting point aluminum cladding on the faying surfaces tends to decrease weld strength

Table 16—Minimum Electrode Clearance Specified in Industry

Offset Electrode



	Vought-Sikorsky			Boeing	Lockheed and Vega. Flange A must not exceed following values for given values of B for any one gauge	
Gauge	A, Min.	B, Min.	B, Desired		B	Max. A
0.016	1/2	7/8	1 1/4	B must not be less than $1\frac{1}{2}$ For any specific value of A, $B = \frac{\sqrt{42.6(A - 0.32)}}{B = \infty}$	...	...
0.020	1/2	"	"		...	...
0.025	1/2	"	"		...	...
0.032	5/8	1 3/32	1 9/16		1	9/16
0.040	5/8	"	"		1 1/2	3/4
0.045	5/8	"	"		2	3/4
0.051	5/8	"	"		2 1/2	15/16
0.064	5/8	"	"		3	13/16
0.072	11/16	1 13/64	1 23/32		...	...
0.081	3/4	1 5/8	1 7/8		...	...
0.093	3/4	"	"		...	...
0.102	13/16	1 27/64	2 1/32		...	...
0.125	7/8	1 17/32	2 3/16		...	...

In general, B Min. = 1.75 A.
B, Des. = 2.5 A.

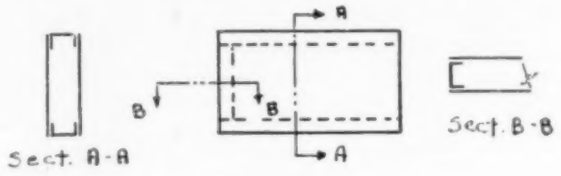
(All dimensions in inches)

consistency. On the other hand, the aluminum clad alloys usually offer less difficulty in so far as electrode pick-up is concerned and can probably be welded at a faster rate.

Shrinkage cracks in weld metal are almost entirely confined to copper-bearing alloys such as 24S and 17S while the chromium-bearing alloys such as 52S and 53S, particularly when hardened, have a far greater tendency to porosity and cavitations inside the weld.

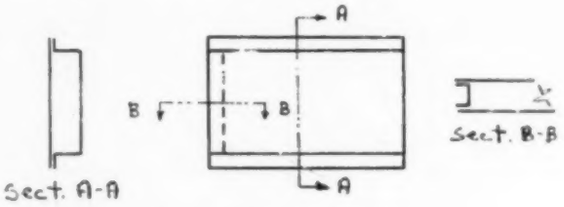
In joining dissimilar alloys, it must be remembered that alloys possessing more nearly similar electrical resistivity and melting points are the easiest to join while, conversely, the alloys possessing the most different electrical resistivity and melting points are the hardest to join. Accordingly, the fully heat-treated or cold-worked alloys weld together comparatively easily while the soft or fully annealed alloys are more difficult to join to fully heat-treated or cold-worked alloys. Similarly, pure or nearly pure aluminum, such as 3S and 2S, has higher melting point than copper- or magnesium-bearing alloys and is more difficult to join to these alloys than to itself.

In joining different alloys, it must be remembered that gauge combinations, as well as materials, play an important part in the weldability of the joint. In general, more heat will be generated in an alloy possessing higher electrical resistivity and the heat generated will be conducted more slowly from the thicker section, thus causing greater weld penetration in such alloys and such thicknesses. Since proportionate penetration is desirable and some penetration is essential for good welding, it is obvious that while a thin section of low resistivity alloy to a heavy section of high resistivity alloy combination may be hard to weld, a reverse combination of a heavy section of low resistivity alloy to a thin sec-



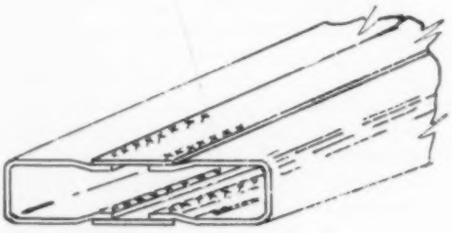
Bad Design

Very poor design for spot welding.
More welded joints than necessary.
Joints almost completely unaccessible.
Requires special machine set-up with special arms and electrodes.
Practically impossible to produce good welding.



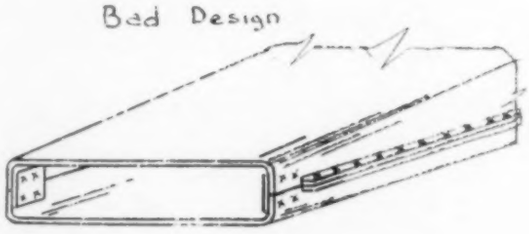
Good Design

Good production design.
Two longitudinal joints instead of four.
All welds accessible, normal technique and electrodes can be used.



Bad Design

Poor production and spot-welding design.
Excessive number of parts.
Parts must be jig-drilled and preassembled.
Weld accessibility poor.
Special machine set-up, technique, electrodes and electrode-arms required.



Good Design

Excellent production and spot-welding design.
Less parts to make.
Two joints instead of four.
Majority of welds readily accessible.

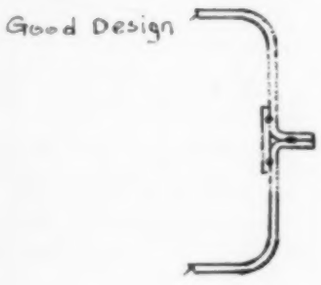
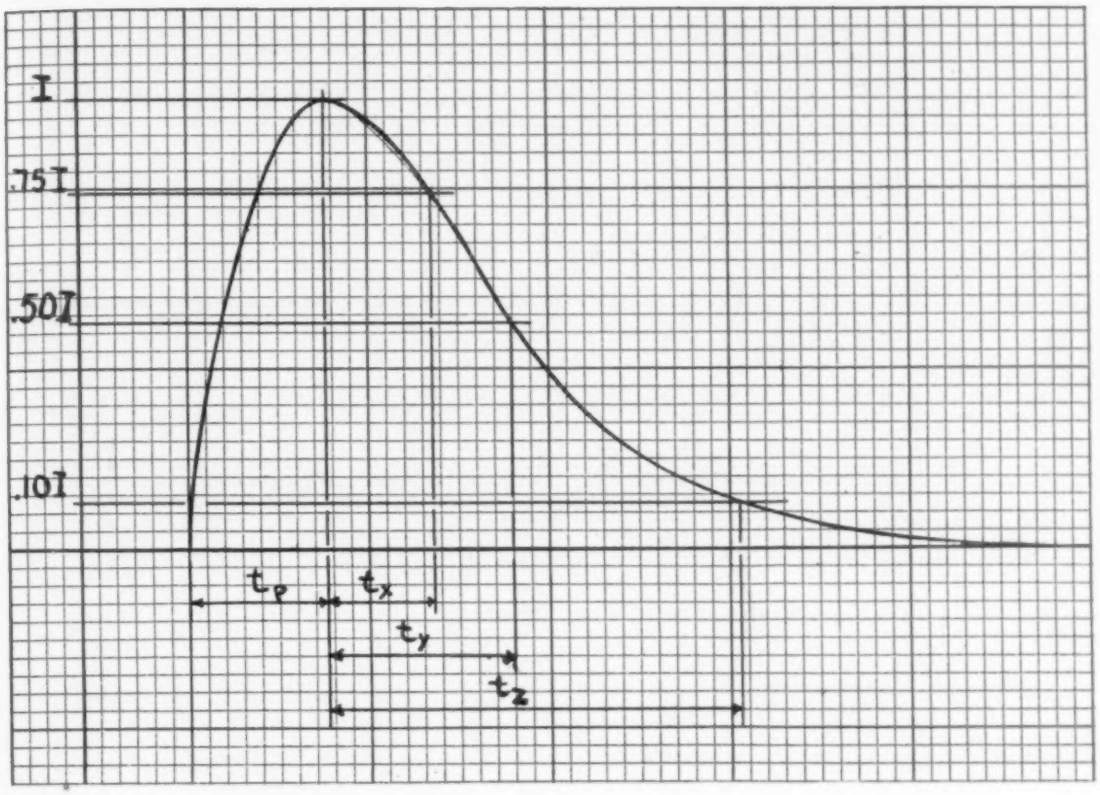


Fig. 27—Good and Bad Types of Spot-Welded Joint Design

Table 17—Weldability of Aluminum Alloys

Top Sheet—Max. of Total Indentation (Domed Electrode)

| Alloy | % Elect. Conduct. | Hard ness* | Sheet thickness Ratio = $\frac{t \text{ bottom}}{t \text{ top}}$ | Bottom Sheet—No Indentation (Large Flat Electrode) | | |



$$I \begin{matrix} \leqq \\ \geqq \end{matrix} \begin{matrix} 1.025 I_a \\ 0.975 I_a \end{matrix}$$

where I is peak current at any one control setting

$$I_a = \frac{I_1 + I_2 + I_3 + \ldots I_n}{n}$$

$$n \geqq 100$$

$$t_p \begin{matrix} \leqq \\ \geqq \end{matrix} \begin{matrix} 1.05 t_{pa} \\ 0.95 t_{pa} \end{matrix} \qquad t_x \begin{matrix} \leqq \\ \geqq \end{matrix} \begin{matrix} 1.05 t_{xa} \\ 0.95 t_{xa} \end{matrix}$$

$$t_y \begin{matrix} \leqq \\ \geqq \end{matrix} \begin{matrix} 1.05 t_{ya} \\ 0.95 t_{ya} \end{matrix} \qquad t_z \begin{matrix} \geqq \\ \leqq \end{matrix} \begin{matrix} 1.05 t_{za} \\ 0.95 t_{za} \end{matrix}$$

where t_{pa}, t_{xa}, t_{ya}, t_{za} are average values of t_p, t_x, t_y, t_z determined similarly to I_a.

Fig. 29—Welding Current Accuracy—Direct Current Equipment

The detailed description of the various types of equipment now available does not rightly fall within the province of these Standards and Recommended Practices and it is recommended that this information be obtained direct from the designers and manufacturers of the equipment now being offered by the trade. However, the broad purpose of the equipment as well as its general standards of performance and capacity rating are a function of the process and are, therefore, discussed here in some detail.

2. The General Types of Spot Welding Equipment

In general the spot welding equipment now available for spot welding of aluminum alloys can be divided into two types; first, conventional alternating current equipment and, second, stored energy equipment.

The latter type is at present further subdivided into electromagnetic type wherein the energy is stored in an electromagnetic field present in an induction coil or reactor, and the electrostatic or condenser discharge type wherein the energy is stored in an electrostatic capacitor.

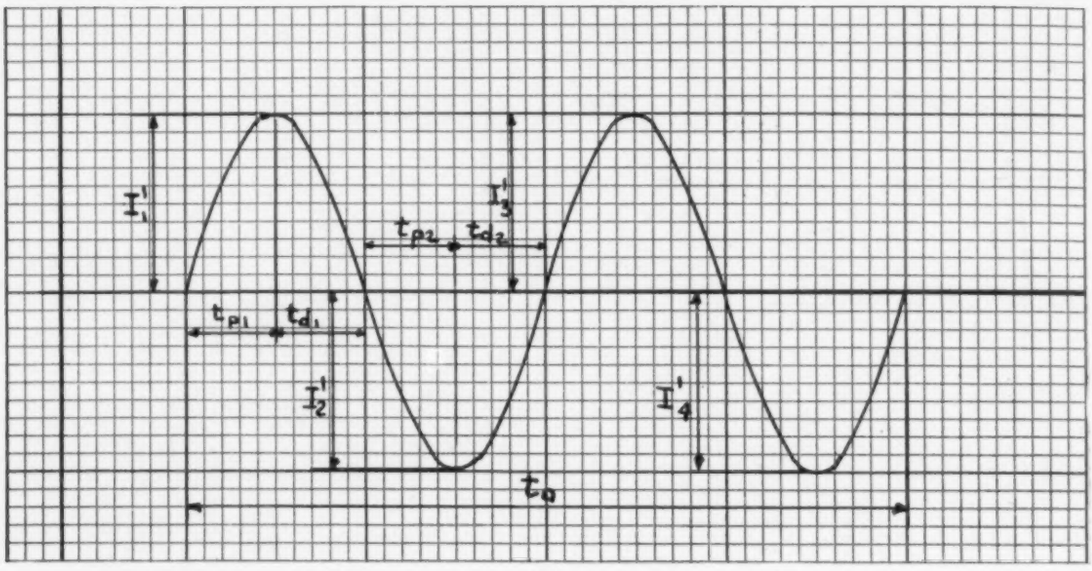
In addition, the equipment may be of the constant pressure type wherein a constant force is applied to the welding electrode, or of the variable pressure type wherein the magnitude of the force is varied during the welding cycle.

From the point of view of welding technique alone, the principal difference between the different types of welding equipment is the difference in the heat-pressure cycle utilized in the formation of the weld. The conventional A.C. equipment is usually designed and is operated with the comparatively long, low-temperature gradient, thermal cycle while the condenser discharge equipment is operated with an extremely short, steep-temperature gradient thermal cycle. The electromagnetic type, because of its inherent preheat cycle, falls in between these two extremes.

From the operating point of view, however, each type, in fact even each make of equipment presents a number of specific points which may or may not be desirable, depending on the conditions in the fabricator's plant and to some extent on his own personal preference and experience.

For instance, alternating-current equipment of the conventional type may be entirely satisfactory for certain applications in plants with unlimited power supply and good voltage regulation and conversely may be entirely unsatisfactory in plants with inherently unstable voltage conditions or in remote locations far away from the source of power.

Accordingly, the selection of the particular type or make of welding equipment should be left to the discretion of the welding engineer and of the welding supervisor who know best the conditions prevalent in their plant, and the personnel available for the operation and maintenance of the equipment.



In case of alternating or pulsating currents the accuracy shall be considered as follows:

Case 1:

$$I' \begin{matrix} \leqq 1.05 I'_a \\ \geqq 0.95 I'_a \end{matrix}$$

where $I'_a = \dfrac{I'_1 + I'_2 + I'_3 + \ldots I'_m}{m}$ and $m \geqq 4$

In this case the rms. value of all current peaks shall be considered as the magnitude I and

$$I \begin{matrix} \leqq 1.025 I_a \\ \geqq 0.975 I_a \end{matrix}$$

where I is the welding current at any one control setting

$$I_a = \frac{I_1 + I_2 + I_3 + \ldots I_n}{n} \text{ and } n \geqq 100$$

Case 2.

$$I' \begin{matrix} \geqq 1.05 I'_a \\ \leqq 0.95 I'_a \end{matrix}$$

In this case

$$I'_1 \begin{matrix} \leqq 1.025 I'_{1a} \\ \geqq 0.975 I'_{1a} \end{matrix} \text{ and } I'_2 \begin{matrix} \leqq 1.025 I'_{2a} \\ \geqq 0.975 I'_{2a} \end{matrix} \ldots I'_n \begin{matrix} \leqq 1.025 I'_{na} \\ \geqq 0.975 I'_{na} \end{matrix}$$

where $I'_{1a} = \dfrac{I'_{11} + I'_{12} + I'_{13} + \ldots I'_{1n}}{n}$

$$I'_{2a} = \frac{I'_{21} + I'_{22} + I'_{23} + \ldots I'_{2n}}{n}$$

etc., etc., n being $\geqq 100$

In general

$$t_{p1} \begin{matrix} \leqq 1.05 t_{p1a} \\ \geqq 0.95 t_{p1a} \end{matrix}$$

where $t_{p1a} = \dfrac{t_{p11} + t_{p12} + t_{p13} + \ldots + t_{p1n}}{n}$

and $$t_{p2} \begin{matrix} \leqq 1.05 t_{p2a} \\ \geqq 0.95 t_{p2a} \end{matrix}$$

where $t_{p2a} = \dfrac{t_{p21} + t_{p22} + t_{p23} + \ldots + t_{p2n}}{n}$

etc., etc., for all t_p until t_{pm}
where $n \geqq 100$ and m = number of peaks.

Similarly $t_{d1} \begin{matrix} \leqq 1.05 t_{d1a} \\ \geqq 0.95 t_{d1a} \end{matrix}$ $t_{d2} \begin{matrix} \leqq 1.05 t_{d2a} \\ \geqq 0.95 t_{d2a} \end{matrix}$
etc., etc.

where t_{d1a}, t_{d2a} correspond to t_{p1a}, t_{p2a}, etc.

In case of alternating or pulsating currents whose period is a function of the power line frequency

$$t_{p1} = t_{p2} = t_{p3} = \ldots = t_{pm}$$

and

$$t_{d1} = t_{d2} = t_{d3} = \ldots = t_{dm}$$

Therefore in such cases it shall be sufficient that

$$t_0 \begin{matrix} \leqq 1.05 t_{0a} \\ \geqq 0.95 t_{0a} \end{matrix}$$

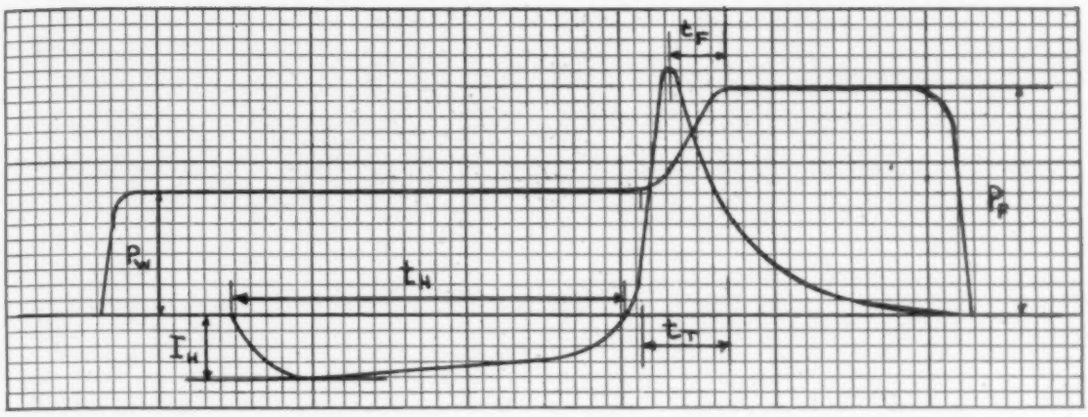
where $t_{0a} = \dfrac{t_{01} + t_{02} + t_{03} + \ldots t_{0n}}{n}$

$n \geqq 100$

Fig. 30—Welding Current Accuracy—Alternating-Current Equipment

There are, however, certain basic standards of output which all welding equipment intended for welding aluminum alloys must meet if it can be considered as at all suitable for this task. To understand these fundamental standards it must be remembered that from the point of view of welding alone, a welding machine is a means to produce a certain thermal cycle at a point of joining, combined with a means to produce a certain pressure cycle at that same point. Unless these two cycles can be reproduced by the machine indefinitely and with close accuracy and consistency, the welding machine cannot be considered as satisfactory since of all the various factors entering into formation of the weld, the above two factors are the ones most capable of accurate control and the ones whose accuracy, therefore, should be taken completely for granted.

The source of energy necessary to fuse the parent metal at the point of joining is provided at present by a flow of electrical current of certain definite magnitude and duration. In addition, the thermal cycle is affected by the heat absorption properties of the welding electrodes applying pressure and current to the weld. The welding machine, accordingly, must be capable of accurate and repeated reproduction of an electrical current impulse or impulses of a certain predetermined shape and, in addition, must be capable of maintaining the same rate of heat absorption by the welding electrodes at each successive weld. In a similar fashion, it must be capable of



$$I_H \begin{matrix} \leqq \\ \geqq \end{matrix} \begin{matrix} 1.05 I_{Ha} \\ 0.95 I_{Ha} \end{matrix} \qquad \text{where } I_{Ha} = \frac{I_{H1} + I_{H2} + I_{H3} + \ldots + I_{Hn}}{n}$$

$$n \geqq 100$$

$$t_H \begin{matrix} \leqq \\ \geqq \end{matrix} \begin{matrix} 1.10 t_{Ha} \\ 0.90 t_{Ha} \end{matrix} \qquad P_W \begin{matrix} \leqq \\ \geqq \end{matrix} \begin{matrix} 1.05 P_{Wa} \\ 0.95 P_{Wa} \end{matrix} \qquad P_F \begin{matrix} \leqq \\ \geqq \end{matrix} \begin{matrix} 1.05 P_{Fa} \\ 0.95 P_{Fa} \end{matrix} \qquad t_F \begin{matrix} \leqq \\ \geqq \end{matrix} \begin{matrix} 1.05 t_{Fa} \\ 0.95 t_{Fa} \end{matrix}$$

$$\frac{P_F - P_W}{t_T} = C \begin{matrix} \leqq \\ \geqq \end{matrix} \begin{matrix} 1.10 C_a \\ 0.90 C_a \end{matrix}$$

where t_{Ha}, P_{Wa}, P_{Fa}, t_{Fa}, C_a are determined in the similar manner.

Fig. 31—Preheat Current and Pressure Accuracy

producing accurately and repeatedly a pressure cycle of predetermined magnitude, duration and relationship to the thermal cycle.

It is recommended that the equipment intended for spot welding of aluminum alloys be capable of the following standards of accuracy in delivering their output of welding current and pressure:

(a) The spot welding machine shall be capable of reproducing indefinitely, at predetermined intervals, impulses of welding current either direct or alternating, the magnitude of which, that is, the peak value of each impulse, does not vary more than $\pm 2\frac{1}{2}\%$ of the average, while the time of occurrence of each such peak from the instant of the beginning of the flow of current, as well as the time from the occurrence of such peak to its decay to a value of 75%, 50% and 10% of the peak, shall not vary more than $\pm 5\%$ of the average as illustrated in Figs. 29 and 30.

(*b*) When the main welding current impulse is accompanied by either a preliminary or subsequent auxiliary impulse of current of not more than $\frac{1}{2}$ value in magnitude, the accuracy of this preliminary or subsequent current impulse shall be not less than $\pm 5\%$ in magnitude and $\pm 10\%$ in duration, the percentage of accuracy to be determined in the same manner as stated above for the main welding impulse and as illustrated in Fig. 31.

(*c*) The welding machine shall be capable of reproducing indefinitely a pressure cycle of predetermined magnitude and duration, the accuracy of which shall not vary more than $\pm 5\%$ of the average in magnitude if the pressure remains constant throughout the welding cycle. In case of a variable pressure cycle, the magnitude of both the welding and forge pressure shall not vary more than $\pm 5\%$ of their average value, and the time interval between the peak value of current and the time the forging pressure reaches the maximum value shall not vary more than $\pm 10\%$ of the average value of such time interval, as illustrated in Fig. 31. In addition, the rate at which the welding pressure is increased to the forging pressure shall not vary more than $\pm 10\%$ of the average value of this rate of rise, as illustrated in Fig. 31.

3. Methods of Rating of Spot Welding Equipment

There are a great many ways in which any apparatus can be rated. The spot welding equipment has been usually rated in the past either by the load it imposed upon the electrical power lines feeding the equipment or even more often by the thermal capacity of the electrical transformer forming part of the machine when operated at a certain duty cycle. This method of rating, although indicating to some extent the general capacity and size of the machine, is unsatisfactory in a great many respects, most obvious of which is that it does not give an exact indication of the output of the welding machine and, therefore, of its true welding capacity.

Recently there has been a tendency, particularly in selection of aluminum spot welders, to specify a certain range of metal thicknesses the machine would weld. This is fundamentally the most sound method of rating welding equipment since it deals directly in terms of the usefulness and range of the machine in so far as its primary purpose, that of joining parts, is concerned.

Unfortunately, the sentence "would weld" is capable of very wide interpretation unless the quality of the weld is carefully defined and because of this, considerable variation existed in the true capacity of supposedly identical machines when rated by this method. However, since the quality of acceptable welding is defined in these Standards, it is recommended that the method of rating the welding equipment in terms of the gauge thicknesses it will weld, be universally adopted as follows:

All machines shall be rated in terms of maximum and minimum metal gauge thickness combinations the machine can weld in production at a stated rate of speed and with the general quality of welding and process control in accordance with these Standards.

It is further recommended that the spot welding machines intended for welding aluminum be divided into three sizes as follows:

Size 1. Min.—2 thicknesses of 0.012 in. or thinner 24St Alclad sheet.

Max.—2 thicknesses of 0.035 in. 24St Alclad sheet.

Size 2. Min.—2 thicknesses of 0.030 in. 24ST Alclad sheet.
Max.—2 thicknesses of 0.081 in. 24ST Alclad sheet.

Size 3. Min.—2 thicknesses of 0.064 in. 24ST Alclad sheet.
Max.—2 thicknesses of 0.110 in. or thicker 24ST Alclad sheet.

It is also recommended that the manufacturer furnish the following information which shall be regarded as part of the rating of the machine:

For Alternating Current Equipment:

(*a*) Maximum kva. demand at 100% rated voltage.
(*b*) Maximum duty cycle at which machine can be operated at maximum kva. demand without exceeding stated temperature rise.
(*c*) Maximum and minimum rms. secondary current machine can deliver at 100% rated voltage.
(*d*) Maximum and minimum electrode pressure machine can deliver consistently and accurately.
(*e*) The extent of the movement in the horizontal and vertical plane of the top and bottom electrodes upon application of the maximum pressure as given above, the measurement to be made with two domed electrodes applying full pressure to a hardened steel plate 1/4 in. thick or greater, ground to a smooth finish and lubricated with machine oil to simulate conditions existing during formation of a weld, that is, with liquid metal acting as a lubricant between the sheets welded.
(*f*) Time cycle of each welding stroke at the maximum rate of operating speed, that is, the ratio of time the electrodes are in contact with the parts being welded, thereby restraining any movement of the parts being welded, to the total time of the operating stroke.

For Stored Energy Equipment:

(*a*) Maximum kva. demand at 100% rated voltage.
(*b*) Maximum impulse of secondary current machine can deliver including time to reach peak, magnitude of peak and time to decay to 10% value of peak.
(*c*) Minimum impulse of secondary current machine can deliver including time to reach peak, magnitude of peak and time to decay to 10% of peak value.
(*d*) Longest possible time to reach any one peak welding current, including approximate wave shape if the rate of growth is non-uniform.
(*e*) Shortest possible time to reach any one peak welding current, including approximate wave shape if rate of growth is non-uniform.
(*f*) Maximum and minimum welding and forging pressures which the machine can deliver consistently and accurately.
(*g*) The time of application of the forging pressure, if different from the welding pressure, as related to the peak current.
(*h*) The extent of the movement in the horizontal and vertical plane of the top and bottom electrodes upon application of the maximum pressure as given above, the measurement to be made with two domed electrodes applying full pressure to a hardened steel plate 1/4 in. thick or greater, ground to a smooth finish and lubricated with machine oil to simulate conditions existing during formation of a weld, that is, with liquid metal acting as a lubricant between the sheets welded.
(*j*) Time cycle of each welding stroke at the maximum rate of operating speed, that is, the ratio of time the electrodes are in contact with the parts being welded, thereby restraining any movement of the parts being welded, to the total time of the operating stroke.

4. Methods of Testing New Types of Welding Equipment

There is no completely adequate test which would predetermine the performance of a welding machine in production since any such test or tests would have to involve all the variables which are encountered in production in a particular plant and would, therefore, be as extensive and complicated as the actual production operation. It is, therefore, generally recognized that the final acceptance or approval of a different or new type welding machine only can be determined by operation of the machine in actual production.

Tests, however, can be devised which will show some of the more obvious inherent weaknesses in a new type of equipment which would tend to make the machine perform unsatisfactorily in production. Since the installation and operation of any piece of apparatus in production involve considerable expense and in case of unsatisfactory equipment may result in additional expense in both loss of time and spoilage of material, it is recommended that such tests be conducted on any new or unproved type of welding equipment prior to its installation and operation in actual production.

It is further recommended that this preliminary test of new or unproved type of welding equipment shall consist of the following:

Test of New Type of Equipment:

(*a*) Shear Pull Test for every metal and every gauge combination that the machine is intended to weld in production.
(*b*) Strength Consistency Test for every metal and in the following gauge combinations that the machine is intended to weld in production:
Thinnest gauge to thinnest gauge
Thickest gauge to thickest gauge
Thinnest gauge to thickest gauge

The Standard Strength Consistency Test shall be modified for this purpose to consist of 100 instead of 25 shear pull specimens with 75 specimens exhibiting consistency of ±10% and 25 specimens of ±20%.

(*c*) Weld Metal Structure Test for every metal and gauge combination that the machine is intended to weld in production.

These tests shall be made with the welding schedules recommended by the manufacturer of the equipment, or, in the absence of such recommended welding schedules, with the welding schedules which, in the opinion of the engineer conducting the test, will produce the best results.

The results of the tests shall be such as to prove the machine capable of producing good welding as defined under Section I of these Standards.

Failure of the machine to pass the above preliminary tests should be considered as an indication of the general unsuitability of the new type for aluminum welding. However, its ability to pass the above tests shall not be construed as constituting unqualified acceptance of the new principle or design involved, but merely as an indication of the suitability of the machine to be tried out in actual production.

5. Measurement of Current and Pressure Output

A measurement of the electrical and mechanical output of a welding machine is frequently necessary for two reasons: first, to determine the exact output at various settings of a new machine and thus permit intelligent application of established welding technique to the new apparatus, and, second, as a check on operation of either new or faulty equipment.

In either case the determination of the current and pressure output has to be made with extreme accuracy and usually permanent record of its measurement is desired.

The following methods are recommended:

(*a*) *Current Measurement.*—Measurement of either A.C. or D.C. welding current is usually considerably more simple if made on the primary or high-voltage side of the welding transformer or reactor. Unfortunately, under some conditions large magnetizing currents may be present in the primary, changing the normal ratio of current transformation. Accordingly, it becomes necessary to determine if and when such magnetizing currents are present by measuring simultaneously both the primary and the secondary currents at different outputs, thus establishing the true ratio of transformation for the entire range of current output. Once the true ratio is established, all current measurements should be made on the primary side, both for the reason of greater simplicity in measurement and also because such measurements can be made without affecting the electrical characteristics of the welder circuit which frequently occurs during secondary current measurement.

The measurements of both primary and secondary currents may be conducted by means of a suitable current transformer or calibrated current shunt. The current transformer, however, can be used only for sinusoidal currents, and should be, therefore, confined to the measurement of the primary current of standard A.C. equipment. A calibrated current shunt should be used for all non-sinusoidal currents either primary or secondary.

It is recommended that the actual current measurement and record be made by means of a standard magnetic oscillograph.

Any suitably calibrated current shunt of the precision type such as, for instance, manufactured by the Weston Electric Manufacturing Company may be used for the determination of the primary current. It is recommended that a shunt consisting of a cylindrical section of manganin placed in series with one of the electrodes and forming part of the electrode holder, of the type first developed at the Rensselaer Polytechnic Institute, be used for the measurement of the secondary current.

It must be remembered that the introduction of a shunt into the secondary circuit will increase the resistance of this circuit. This increase may be of sufficient magnitude, particularly in stored energy equipment, to affect appreciably the welding current. This change in the welding current has no significance in laboratory or experimental work since it can be easily corrected by suitable changes in the normal adjustments of the machine's controls. However, since it is obviously impractical to equip every production machine with a secondary shunt, an appreciable error may be introduced into the current calibration of a production machine at its normal control settings if the current at each setting is determined by the use of a secondary shunt. It is for this reason that the use of the secondary shunt is recommended only as a means for determining proper transformation ratio.

For detailed description of suitable secondary shunts see "The Measurements of Spot Welding Current," by W. F. Hess, *A.I.E.E. Transactions*, June 1940.

In checking the operation of equipment in production it is frequently desirable to obtain a quick check on the approximate consistency of the current output without actually measuring the current. In such cases a ballistic ammeter with a stop hand indicating the momentary swing of the meter needle can be used with a fair degree of satisfaction.

(*b*) *Pressure Measurement.*—The measurement of the static welding pressure, that is, of the force developed by the machine and applied at the welding electrodes, should be measured directly at the tips of the welding electrodes, with a suitable mechanical, pneumatic or hydraulic gauge. Several such gauges are now available and are satisfactory for use, provided their calibration is checked periodically on a suitable testing machine.

Such static measurements are satisfactory for indicating the pressure capacity of the equipment. They do not, however, give the true welding pressure at the time of welding as they do not take into account the dynamic forces developed during the formation of the weld, such as the electromagnetic repulsion of the electrode and electrode holders and arms, the inertia effect of the movable system during the follow-up period, the possible movement of the electrodes in the horizontal plane, etc.

There is no standard dynamic pressure gauge available on the market now, though several are in the process of development. Of these, the three most promising are based on the same principle, namely, the change in electrical sensitivity of a fine wire or series of wires when subjected to a variable tension load. These gauges are built into a standard electrode holder permitting their use under production or semi-production conditions. The complete description of the operation of these gauges may be found in the following:

Hess, W. F., and Wyant, R. A., "Electrical Measurement of Electrode Pressure During Spot Welding," THE WELDING JOURNAL, October 1941.

"Device for Measuring Tip Force and Current in Spot Welding," General report 2561, Lockheed Aircraft Corporation.

North American Aviation, Inc., Reports LN-3562 and LN-3155.

6. Installation of Welding Equipment

Installation of all electrical and mechanical machinery is generally governed by a number of well-known rules, which should be followed in case of welding equipment also. However, the welding equipment differs from the other electrical and mechanical machinery in several respects and there are, accordingly, some specific rules which should be followed if the equipment is to be capable of producing welding of the quality required by these Standards and is to operate in the most efficient manner.

It is therefore, recommended that the following rules be observed in installing welding equipment:

(*a*) The maximum permissible line voltage fluctuation of the power supply feeding alternating-current equipment shall not exceed ±5% of the average line voltage during any one operating shift.

(*b*) The maximum voltage drop on any one power bus feeding two or more welding machines due to the operation of any one of such machines shall be not more than 10% of the normal line voltage unless the operations of the machines are so interlocked that no two or more machines can operate simultaneously.

(*c*) During the operation of any one welding machine the voltage at the terminals of that machine shall not drop below 85% of the maximum voltage at that machine during its operation, for any cause whatsoever other than the operation of the machine itself.

(*d*) The water supply for cooling a welding machine and its electrodes shall be of such capacity that the water pressure at the intake into the welding machine shall not be less than 20 psi. at any time and with water circulating freely throughout the machine.

(*e*) It is recommended that the temperature of the incoming cooling water does not exceed 40° F. At no time shall the temperature of the incoming cooling water exceed 75° F.

(*f*) The cooling water as furnished to the welder shall be clean and free from all foreign substances which may tend to corrode or clog the water-cooling tubes.

(*g*) The pressure of air furnished to the pneumatically operated spot welders shall not be less than 80 psi. at any time. In case the equipment has to be operated in location where fluctuation in air pressure may cause it to drop below 80 psi., low air pressure alarm shall be installed which will become operative whenever the air pressure drops below 80 psi. It is recommended that no welding equipment is operated on air supply of over 125 psi. unless it is specifically designed for such duty.

(*h*) It is recommended that the air supply to the pneumatically operated equipment is kept clean and free of water by means of suitable air filters and water traps installed at each machine.

(*j*) It is recommended that ample clearances be provided around all electrical control apparatus used in conjunction with welding equipment, particularly so in case of stored energy equipment where high voltages or high voltage surges may be expected.

7. Maintenance of Welding Equipment

It must be recognized that all forms of welding equipment developed to date for spot welding of aluminum alloys are considerably more complicated and elaborate than the average type of equipment used in industrial production. All possible stress must be laid, therefore, upon provisions for proper maintenance of the welding equipment.

Specifically the following recommendations are made:

(*a*) A maintenance man shall be assigned to and continually be available for each one group of not over twenty (20) welding machines being operated on any one shift.

(*b*) The maintenance men assigned to the welding equipment shall receive special instructions in the operation and construction of the welding equipment under their charge and shall be thoroughly familiar with its design, operation and construction.

(*c*) Periodic inspection of the equipment, including complete overhaul of all parts which have been found to give trouble, shall be conducted on each spot welding machine not less than once every two weeks and preferably every week.

(*d*) All maintenance and adjustment of the welding equipment, except such adjustments as are called for on the welding schedules, shall be conducted either by the welding engineer or by the maintenance men or any other authorized individuals who have received special instruction in the operation, design and construction of the welding equipment.

8. Welding Electrodes

The welding electrodes constitute the only part of a welding machine which require continual replacement and which, therefore, must be stocked and purchased in considerable quantities. Since there is considerable variation in the shape of parts encountered in aircraft, a great variety of electrode shapes is frequently necessary. There are, however, certain types of straight electrodes which are used in considerable quantities on all flat and accessible work.

Since considerable saving in cost can be accomplished if the dimensions of the electrodes most widely used are standardized, it is recommended that whenever possible the straight electrodes used shall be in accordance with Fig. 32.

It will be noted that the electrode contours given in Fig. 32 are 10 in. and 2 in. radius, respectively.

It is recommended that whenever different radii are required, these be machined by the fabricator since he has to provide facilities for the machining of the electrode contours anyway for restoration of used electrodes.

It is recommended that ejector type electrode holders providing not less than two (2) gallons per minute water flow through the electrode at 25 lb. water pressure be used with these electrodes.

It is further recommended that these ejector type holders shall be furnished in $1^1/_4$ and $1^1/_2$ in. diameters and in 8-in., 10-in., and 12-in. lengths.

Section VIII—Personnel

1. General

Because of the fully automatic operation of modern welding equipment, temptation exists to assume that the sole function of a spot weld operator is merely to press a button and handle the material to and from the machine. This assumption is never quite justified and particularly so in case of aluminum alloys.

Intelligent operation can improve performance of the most completely automatic equipment even when operating under the most favorable conditions, and in the case of aluminum welding where the control of the spot welding process has to be maintained with the greatest rigidity, as has been shown throughout these Recommended Practices, intelligent execution and supervision of this control are absolutely essential if good results are to be obtained.

Accordingly, selection, training and administration of the personnel entrusted with the welding process from the welding engineer to the welding operator constitute a very important phase of the welding process.

As everywhere else, the welding personnel can be divided primarily into a group composed of operators whose job is to do the actual work, and a supervising group whose responsibility it is to see that the work is done and that it is done in a proper manner. However, whereas in most other manufacturing processes, the job of supervision is primarily to see that work is produced and the quality of the product is mainly left to the efforts of the Inspection Department, the highly technical nature of spot welding makes it imperative that supervision of the process include both a production and a technical man charged with output and quality, respectively.

This section attempts to recommend both the desired qualifications of the welding personnel and the division of responsibility and authority between its various members.

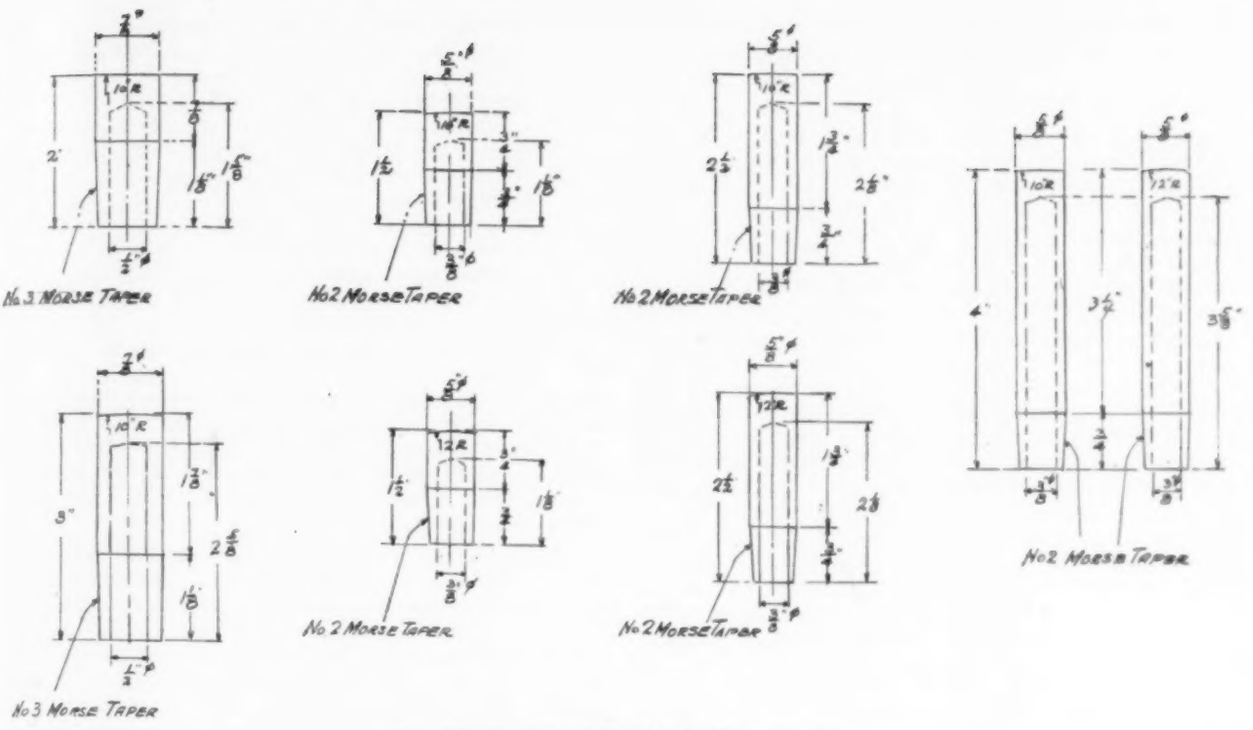


Fig. 32—Standard Electrode Dimensions

2. Welding Operators

It is obvious that the greater the knowledge of the operator concerning the complete welding process, the more dependable will be his work. It is recommended, therefore, that all possible attempt be made to acquaint the operator as much as possible with the various phases of the welding process. It is specifically recommended that training courses or lectures be conducted on company time preferably by the men charged with administration of the Welding Division. It will be found that such courses or lectures, especially when accompanied by discussions between the operators and the lecturer, will soon pay for themselves in improved output and weld quality.

Since there is obviously no limit to the extent of knowledge and experience which can be acquired beneficially by the operators, it is necessary to set a certain minimum requirement of skill and experience which the operator must possess before he can be entrusted with production work.

It is recommended that these minimum requirements be as follows:

(*a*) Ability to translate the welding schedule into machine adjustments and a thorough understanding of the significance of each adjustment called for on the welding schedule.

(*b*) Ability to recognize quality of welding and a clear understanding of how defective welding can be overcome. This in turn requires:
  (1) Thorough knowledge of the Weld Quality Standards.
  (2) Ability to conduct Shear Pull Tests and Weld Penetration Tests.
  (3) Fundamental knowledge of the factors affecting the formation of the weld.

(*c*) Ability to recognize when welding electrodes require cleaning.

(*d*) Ability to clean welding electrodes in the approved manner.

(*e*) A certain amount of manual dexterity and general efficiency permitting the operator to conduct his work with proper speed and dispatch.

(*f*) Ability to understand the proper requirements and function of the part being welded sufficiently to permit intelligent rather than blind assembly operation.

The time required for different operators to acquire the above qualifications will vary extensively, and, therefore, no prescribed minimum time of training period can be recommended. In general, it is recommended that the candidates for the job of welding operator be first made to serve as welding helpers, handling materials and, in general, assisting the welding operators in the work while at the same time be given such instructions as are provided by the company for the training of the welding personnel. In general, more satisfactory results can be obtained with candidates who have not had any previous experience in spot welding other than spot welding of aluminum alloys in aircraft, since considerable difference exists in the techniques and requirements of other forms of spot welding, and as usual it is easier to form new habits than to change old ones.

It is recommended that the responsibility of the welding operators be confined to the following.

(*a*) Quality of welding.

(*b*) Speed of welding.

(*c*) Fit and location of parts when the parts do not reach him preassembled by means of screws, Cleco clamps, tack welds or any other semi-permanent fashion.

Although the maintenance of the equipment is not directly part of the operator's duties, he should be made indirectly responsible for its operation through his direct responsibility for the quality of the welding he is producing which obviously cannot be up to standard with faulty equipment operation. It is, therefore, his responsibility to summon the maintenance man at the first sign of faulty operation of equipment, or if the mainte-

nance man is not available, to suspend welding and to draw the attention of the supervisor to the situation.

3. Production Supervision

Because of the great importance of uniformity of production process control, it is imperative that the final responsibility for all spot welding and the administration of the entire process be confined to one person. For this reason, it is recommended that the production of spot welding in any one plant be made the responsibility of one full-time welding supervisor. The supervisor's work may be carried directly or through as many assistant supervisors, leaders, or set-up men as the extent of the operations and the location of the equipment in the plant may require, provided that the final authority and responsibility for spot welding production output is entirely in the hands of the spot welding supervisor.

It is further recommended that the production supervisor be made fully responsible for the quality of the welding except in cases where the defective quality can be definitely traced to the inadequacy of the welding technique prescribed by the welding engineer.

Since the duties of the supervisor and of the welding engineer overlap to some extent, particularly in so far as weld quality is concerned, it is extremely important that these two men be made to work as closely together as possible. The welding engineer should seek the advice of the welding supervisor in the selection and installation of welding equipment, as well as in the development of new welding techniques and welding processes. Similarly, the welding supervisor should keep the welding engineer continually informed about his experience with the welding processes and equipment under his supervision.

For this reason it is recommended that both quality and quantity of welded output be made the joint responsibility of both the welding supervisor and the welding engineer.

4. Welding Engineer

The spot welding process as used for aircraft production is both new and fairly complicated. Being new it is frequently regarded with skepticism, and being complicated it requires thorough coordination and cooperation of the factors entering into aircraft design and production. For these reasons, if spot welding process is to accomplish in the aircraft industry what it has accomplished in other industries, namely, a tremendous reduction in time and labor, its development and promotion cannot be left in the hands of a number of individuals as part of their duties but must be concentrated in the hands of some one individual suitably qualified for the task. This individual, who for lack of a better name shall here be called the Welding Engineer, must be given the incentive to promote, improve and perfect the processes of spot welding in a plant to the exclusion of everything else.

It is, therefore, recommended that the development of the spot welding processes including the establishment of proper welding techniques, selection and procurement of welding equipment, instruction of welding personnel, as well as the application of the welding processes to the fabricator's product, be placed in the hands of the welding engineer.

The welding engineer then should be responsible for the following:

(*a*) Development of a complete welding process, including materials preparation and material handling methods.

(*b*) Development and establishment of suitable welding technique, including the establishment of proper welding schedules.

(*c*) Quality of the welding—this responsibility to be shared jointly with the welding supervisor.

(*d*) Rate and efficiency of production—this responsibility to be shared jointly with the welding supervisor.

(*e*) Selection and procurement of the welding equipment including proper jigs and fixtures.

(*f*) Development of suitable testing methods.

(*g*) Development of all new welding processes.

(*h*) Proper welding design.

(*j*) Proper application and dissemination of the use of welding.

(*k*) Proper maintenance of the welding equipment either directly by having the man charged with the maintenance of spot welding equipment under his jurisdiction or through the proper access and cooperation with the plant engineer.

Because of these responsibilities of the welding engineer, he should be encouraged to work in close collaboration with the Production and Structural design groups to improve as much as possible the output of welded parts. For this purpose, it is recommended that the welding engineer be given the opportunity and facilities for conducting time studies of welding operations and of the flow and routing of all parts and assemblies to be welded. It is also recommended that all drawings detailing parts to be welded be countersigned by the welding engineer and that he be consulted in all matters pertaining to welding in structural design.

Section IX—Production

1. Production Methods

Spot welding is inherently a mass production, high-speed tool and its use requires that all the usual rules of good production methods are followed as closely as possible if real savings in time and labor are to be realized. These are too numerous and too well known to be repeated here. A few, however, primarily inherent to spot welding and which are apt to be overlooked by the general production experts, may be well emphasized as follows:

(*a*) An average spot welding machine is capable of operating at between 30 and 70 spots per minute depending on gauge combinations welded. It is thus potentially capable of producing 14,000 to 33,000 spot welds per 8-hour shift. However, in order that the machine may even begin to approach such output, it must be kept operating continuously. Although 100% continuous operation of a spot welding machine is obviously impractical because work has to be fed in and out of the machine and a certain percentage of operating time must be given up to permit cleaning of the electrodes and for conducting inspection tests, 50 to 70% continuous operation may be approached provided the following elementary rules are observed:

1. Parts to be welded must be properly routed and kept moving so that there will be plenty of work to be done piled up at each machine at all times.

2. Parts to be joined must be supplied to the machine preassembled in some temporary manner such as screws, Clecos, quick acting clamps, jigs, fixtures, or even tack welds so that the operator need not spend his time fitting the parts together while equipment is standing idle.

3. An attempt should be made to specialize each machine as much as possible, that is, to confine its operation to one particular part or at least one particular gauge combination in order to reduce to a minimum the time consumed in changing over from one machine set-up to another.

4. Adequate supply of welding electrodes of all required types must be provided at each welding machine within easy access of the spot weld operator.

5. Spot weld operators must have immediate and easy access to their supervisors, inspectors and maintenance men.

6. An incentive spirit of accomplishment and competition must be fostered and established by providing means of recording and publicizing the daily production of each machine, group, shift and department. The practice of financial compensation for record achievement of both production and quality is not always practical but its possibility must be borne in mind and it should be utilized whenever possible.

7. All welding activities should be integrated into one welding department under unified supervision and control.

(*b*) Although from a general production point of view, temptation often exists to scatter welding equipment throughout the plant, and thus reduce to a minimum all trucking operations, this procedure is not very satisfactory as a rule because of the many requirements inherent to spot welding equipment which cannot be readily satisfied unless the equipment is concentrated in large groups. It will be found that production of individual spot welders scattered throughout the plant, or of any group of spot welders which do not form a unit large enough to justify its own full-time material preparation, supervision, inspection and maintenance facilities, is extremely low and does not begin to approach the economies and speeds which constitute the very core of the use of spot welding.

2. Production Costs

The costs of spot welding, like all mass production costs, will depend to a large degree on the total volume of production available. Because of the comparatively small use of spot welding in the aircraft industry, the present costs are probably unusually high. Such estimates of spot welding costs as are now available indicate that on a basis of not less than 50,000 spots produced per 8-hour shift, it would be reasonable to expect an average cost of a weld, including equipment depreciation, material preparation, preassembly of parts, and shop supervision and overhead, to be around 4 mills per spot. This cost is applicable to the welding of the types of parts now being welded in the industry, which as a whole are probably the least suited to welding. Whenever long lines of welding on easily accessible parts such as, for instance, stiffener reinforcements to wing skins are welded, permitting the use of roller weld equipment, the cost per weld appears to be not over 1 to 2 mills.

The above figures are based on the present volume of production and present operation methods. It is almost certain that increased application and increased volume of production should result in considerably decreased cost.

Spot Welding Costs

Cost of Spot Welding	Lockheed	Vought-Sikorsky
Using A.C. spot welder	$0.003208* per spot	$0.004 to $0.005 per spot for all types of equipment
Using Electromagnetic spot welder	$0.003137* per spot	
Using Electrostatic spot welder		
Using A.C. roller welder	$0.001607*† per spot	

* Including cost of pre-weld assembly.
† At comparable weld spacing.

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Reclaiming Twist Drills

By G. E. Greaser*

AS MOST of us are well aware, it is becoming more and more difficult to purchase high-speed twist drills. The abnormal demand for drills, coupled with the drill manufacturers' problems of obtaining the necessary materials, machines and skilled labor to produce them, makes it almost certain that the situation will not improve in the near future. It is expedient therefore to conserve carefully any stocks of drills that may be on hand and to use them with greatest care. If, and when, a drill is broken, however, it can be reclaimed with the oxyacetylene blowpipe at a small fraction of its original cost.

Some time ago one plant instituted a program of reclaiming drills by this method. Most of the drills in this plant are of 18–4–1 high-speed steel (18% tungsten, 4% chromium, 1% vanadium), and are used for drilling armor plate and other alloy steels. They are quite expensive in comparison to carbon-steel drills and in these times are difficult to obtain. To date they have salvaged thousands of dollars worth of these drills at a cost of from 5 to 10% of their original purchase price.

Types and Causes of Breakage

In general there are two types of breaks in twist drills. The most common type is the broken or twisted tang. It will be remembered that the shank of a drill which is machined to a standard type of taper is relatively soft (between 275 and 300 Brinell) in comparison with the fluted portion of the drill. The tang of the drill, which fits into the socket of the drill-press spindle, transmits the spindle driving torque to the drill. Consequently it receives punishment, and under extreme conditions of improper seating, excessive feeds, excessive spindle speeds or improperly ground cutting bit, the tang may be twisted or broken off and the drill rendered unusable.

The second type of break, less common than the one mentioned above, is one in which the drill is broken in two at the point where the shank meets the fluted portion. usually it is broken because of carelessness on the part of the drill-press operator, or because of an improperly ground bit. An operator may swing a mounted drill against the drill-press bed and the sudden impact will cause it to snap; or an improperly ground bit may cause the drill to dig in and the torque impact will break the drill rather than the tang. Breakage thus caused is increasing because of the present-day high-speed production and a necessarily higher percentage of inexperienced operators in machine shops.

Tang Repair

Preparation of a drill for a tang repair is quite simple. If the tang is twisted, remove the damaged portion with

* The Linde Air Products Co., Pittsburgh, Pa.

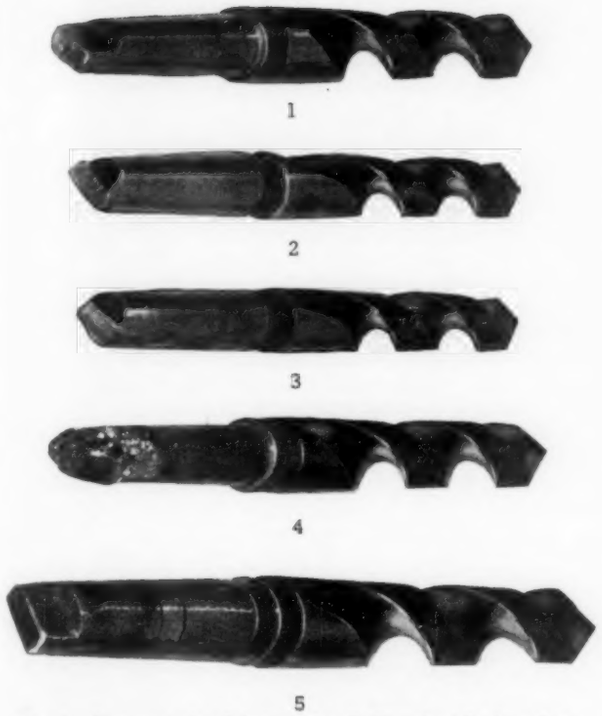

Fig. 1—Stages in the Salvage of a Drill with a Broken Tang
(1) A new drill as received from the manufacturer, (2) the broken tang, (3) the broken surface ground preparatory to welding, (4) built-up tang, and (5) a reclaimed drill ready for service.

a hack saw, but if the tang is broken off, no particular preparation is necessary other than to grind the rough surface of the break slightly. Clamp the drill in an upright position, tang end up, and then build up the new tang, using a welding blowpipe and a suitable rod. The blowpipe head size is governed by the cross section of the tang. It should, however, be held to a minimum.

For the first $^1/_4$ in. of weld deposit, a 2X flame should be used—that is, a flame in which the acetylene feather is twice the length of the inner cone. After the weld has progressed to this point, the flame should be readjusted so that there is only a slight excess of acetylene. The puddle of molten metal should be carefully controlled to avoid blowholes. This may perhaps best be done by using a minimum flame and withdrawing it slowly at the end of a pass. The backhand technique of welding will also help. Some welding operators use a flux for drill work but its value for this type of weld is somewhat questionable.

Figure 1 shows progressive stages in the salvage of a drill with a broken tang: (1) a new drill as received from the manufacturer; (2) the broken tang; (3) the broken surface ground preparatory to welding; (4) built-up tang; and (5) a reclaimed drill ready for service.

After welding is completed, the weld zone should be reheated to a dull red and then buried in asbestos wool, lime or other insulating material, and permitted to cool slowly. When the weld zone is cold, a new tang is then ground or cut on a milling machine.

Broken Shank Repair

A broken shank requires a little more preparation than a twisted tang. A shank usually, if not invariably, breaks at its juncture with the fluted portion of the drill (breakage in the flutes seldom occur except in extra-long drills). Repair of a break of this type consists of substituting a new shank for the old one and bronze-welding it in place. The blank for the new shank should be of 60-point carbon (0.60% carbon) or equal quality and should be of the same diameter as the drill.

Bevel the broken surface on the fluted section by grinding it to a bevel angle of 20 to 30°., leaving a land about $^1/_4$ in. in diameter in the center. The angle of bevel should be held to a minimum, particularly in the larger-size drills, as the hardened high-speed steel is quite tedious to grind. Bevel the shank blank to an angle of 45°, likewise leaving a $^1/_4$-in. land in the center. This procedure provides a welding vee of a 65 to 70° included angle, and also simplifies the lining-up of the drill and the new shank.

After the two parts have been lined up in V-blocks, weld them together, using a bronze rod, and a flame with a slight excess of oxygen. In order to insure good tinning action on the surface of the high-speed steel the heat must be carefully controlled, concentrating it mostly on the shank side of the weld. Some operators feel that a little Ferro flux mixed with the Brazo flux aids the tinning, but here again the value of the Ferro flux is questionable. Build up the weld so that it is larger in diameter than the drill. When it is completed, reheat the weld zone to a dull red or a little less, and then place the drill in the annealing bin to cool slowly.

Fig. 2—A New Shank Welded on to a 3-In. Drill, Before Machining

Fig. 3—The Same Drill Shown in Fig. 2, After the Machining Operations

After the drill is cold, it is chucked in a lathe, and a new standard-type taper is turned on the shank blank. When a blank of the same diameter as the drill is used any eccentricity developed during the welding operation can be taken care of in the excess machining stock.

The built-up bronze of the weld should be turned down so that the collar is somewhat larger in diameter than the drill. Leave the width of the collar intact, however, to serve as a reinforcement.

From the lathe the drill is sent to the milling machine where a tang is cut in the new shank.

Figure 2 shows a reclaimed 3-in. drill before being placed in the lathe, and Fig. 3 shows the same drill after the turning and milling operations were completed, ready to go back into service in just as good condition as when new.

Cracked Drop Hammer Frame Repaired by Welding

By A. P. Demmer*

A HEAVY drop hammer which had given years of service in forging out horseshoes, and more recently was put to work hammering out wrenches on war production work, finally began to give way. A few cracks developed in the main frame casting, but since production schedules had to be met the drop hammer was continued in service until finally it became unsafe to operate. Nine cracks had developed from a defect in the casting, and had worked their way 16 to 20 in. across the frame.

* Supervisor, Air Reduction Sales Co., Minneapolis, Minn.

To restore the drop hammer to service with a minimum of lost production time it was decided, rather than to gouge and weld each of the nine cracks, to cut out the entire defective section and replace it with a welded patch. Accordingly a piece of $1^1/_4$-in. rolled boiler plate was flame cut to match the removed section, and the edges of both the patch and the casting were veed, using a flame-gouging tip.

Two men working alternately welded the 18 by 24-in. plate into place in 18 hr., and the drop hammer was promptly restored to active service. The welding was done in four passes, using all-position shielded arc-welding electrodes. Ordinarily a clean-up weld would have been added but since the completed weld already represented a strength at least equal to that of the casting itself, beauty was neglected in favor of putting the drop hammer back to work without further delay.

Operation of the repaired machine has been completely satisfactory. Without the aid of welding, the restoration to service of this heavy machine would have entailed not only a much greater expense for a replacement casting, but also many months of delay and lagging war production.

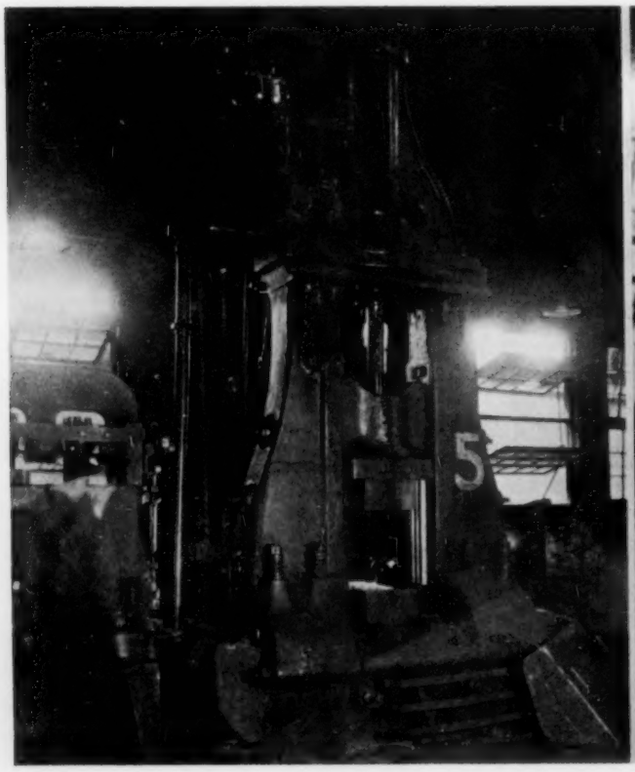

Fig. 1

Lower left section of heavy drop hammer frame has been patched with $^1/_4$-in. boiler plate, replacing defective metal which had become so overrun with cracks that it was unsafe to operate. (Long shot.)

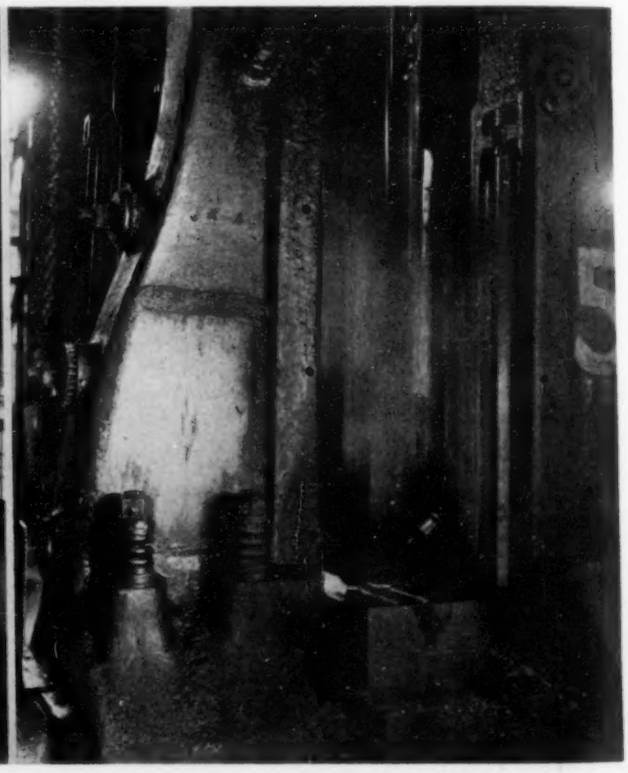

Fig. 2

Again in service after welded repairing, the drop hammer was inactive for only one day while the 18 by 24-in. patch at left was welded into place. Since the machine is used on war production work the shortness of the delay was important. (Close-up shot.)

ANNUAL MEETING

American Welding Society, Hotel Cleveland
October 12–16, 1942

Plan to Attend!

Clear the Lines for the War

Before you make a Long Distance telephone call today, ask yourself these questions:

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THE AMERICAN WELDING SOCIETY

ACTIVITIES — RELATED EVENTS

AMERICAN WELDING SOCIETY HEADQUARTERS—ANNUAL MEETING CLEVELAND HOTEL

The SOCIETY has received word from the Cleveland Hotel that rooms will not be held in reserve for members and guests of the AMERICAN WELDING SOCIETY later than September 15th. The hotel recommends that all reservations be in by September 1st so as to insure being located at the Cleveland Hotel.

The Housing Bureau—designated by the Management of the National Metal Congress and Exposition, and on which every society participating in the Congress has representation—plans to meet in Cleveland on or about August 15th. At that time assignment of rooms will be made. It is recommended, therefore, that if you wish choice location in your Hotel Headquarters you get in your reservation immediately. Notification of room assignment will be sent out on September 1st. Again you are urged to get in your application not later than September 1st if you are planning to attend the Cleveland Convention.

THE PRESIDENT'S MESSAGE

By G. F. Jenks

The Society has completed its plans for the Annual Meeting. It has formulated educational programs directed to the speeding up and perfection of the war program. It recognizes the part that advances in engineering practices through research play in this world struggle. Its program of technical papers includes reports on progress in research and in design and production engineering. It covers aircraft, ships, ordnance and the many products of war.

There are no distinct lines of cleavage between branches of engineering. The welding engineer is concerned with metals and with structures. He needs a knowledge of the methods of production, fabrication and testing of stresses and stress concentrations and of the fundamentals of materials and design. Through participation in the Metal Congress the SOCIETY offers its members the opportunity not only of hearing but of taking part in the discussion of papers, of contacting the leading engineers in the fields of welding and of metals, and of obtaining the advice of the industrial engineers present at the Metal Exhibition. In no other place and at no other time is there gathered the nation's talent in the welding and the metals industries.

The success of our war production programs depends upon cooperative effort. No single individual or single organization can carry on all the development work required for any single product.

The rate of industrial and scientific development is increasing. In some fields textbooks become obsolescent in a few years, in others texts are still to be written. Periodic literature is of growing volume but does not cover all development work nor include the latest investigations.

Personal contacts and conferences must be utilized if the individual engineer is to take advantage of the developments of industry. There can be no substitute for these direct relations. The Metal Congress affords an unusual opportunity for these contacts.

The value of these contacts is not limited to the information obtained for the solution of our current problems. Each individual attending the Congress cannot but be stimulated to deeper thinking and inspired by the spirit that pervades the whole assemblage.

The SOCIETY, in the organization of its annual meeting programs and in the work of its technical committees, receives surprisingly few suggestions from those members who are not charged with direct responsibility. It can but follow that the SOCIETY is not accomplishing all which its membership desires. Our committees and staff may take pride in what the SOCIETY is doing, but there is still a need for greater cooperative effort for the benefit of industry and the nation. It would be of great assistance to the management of the SOCIETY if our membership and friends pointed out where and how the SOCIETY might be of greater service to its members, the community and the nation. It is hoped that the disclosures of the annual meeting will stimulate many to set down on paper ideas for the improvement and extension of our SOCIETY'S service.

MINIMUM REQUIREMENTS FOR INSTRUCTION OF WELDING OPERATORS

The AMERICAN WELDING SOCIETY has recently approved and published a new tentative standard, entitled "Code of Minimum Requirements for Instruction of Welding Operators, Part A—Arc Welding of Steel $^{3}/_{16}$ to $^{3}/_{4}$ In. Thick." This Code was developed over a period of two and one-half years by an A.W.S. technical committee, and fills an important need in the welding field.

The Code as published represents a revision of the "proposed code" that was published in the September 1941 issue of THE WELDING JOURNAL for the purpose of eliciting comments, suggestions and criticisms. In the process of revision, the Code was considerably expanded, particularly with respect to the supplementary material given in the appendices as suggestions to persons organizing courses in metal arc welding. The sections in the main body of the Code include: equipment and facilities of the school, qualifications and duties of the instructor, instruction in welding practice, instruction in welding theory, and final tests. There are nine appendices of suggested and recommended material, as follows: suggested accessory equipment for welding schools, recommended design of positioning equipment, recommended designs of testing apparatus and their application, recommended safety rules for student arc-welding operators, welding electrodes, suggested arc-welding exercises, suggested form of student progress chart, recommended form for record card, annotated selected bibliography of publications relating to arc-welding instruction.

This Code was published in the form of a 68-page booklet with a heavy paper cover, and is available at 50¢ per single copy with discounts for quantities. Orders should be accompanied by check, money order or cash, and addressed to the AMERICAN WELDING SOCIETY, 33 West 39th St., New York City.

SPOT WELDING OF ALUMINUM ALLOYS IN AIRCRAFT

The AMERICAN WELDING SOCIETY has recently approved and published a committee report on the above subject, entitled "Emergency Standards and Recommended Practices and Procedures for Spot Welding Aluminum Alloys." This report is the result of nine months of concentrated work by the Committee and represents tentative recommendations for standards of weld quality and performance as well as general recommendations of the best practices and procedures to be followed in spot welding of aluminum alloys in the aircraft industry. It also contains a general discussion of the theory of spot welding, particularly as applied to aluminum in the aircraft industry. The subjects covered include standards of weld quality, surface preparation for spot welding, welding technique, methods of testing, methods of inspection, design of spot-welded parts, welding equipment and installation, as well as a short dissertation on personnel requirements and production methods. The report was prepared by a committee composed primarily of welding engineers of various aircraft companies and is an attempt to provide a practical guide and a reference book to any one en-

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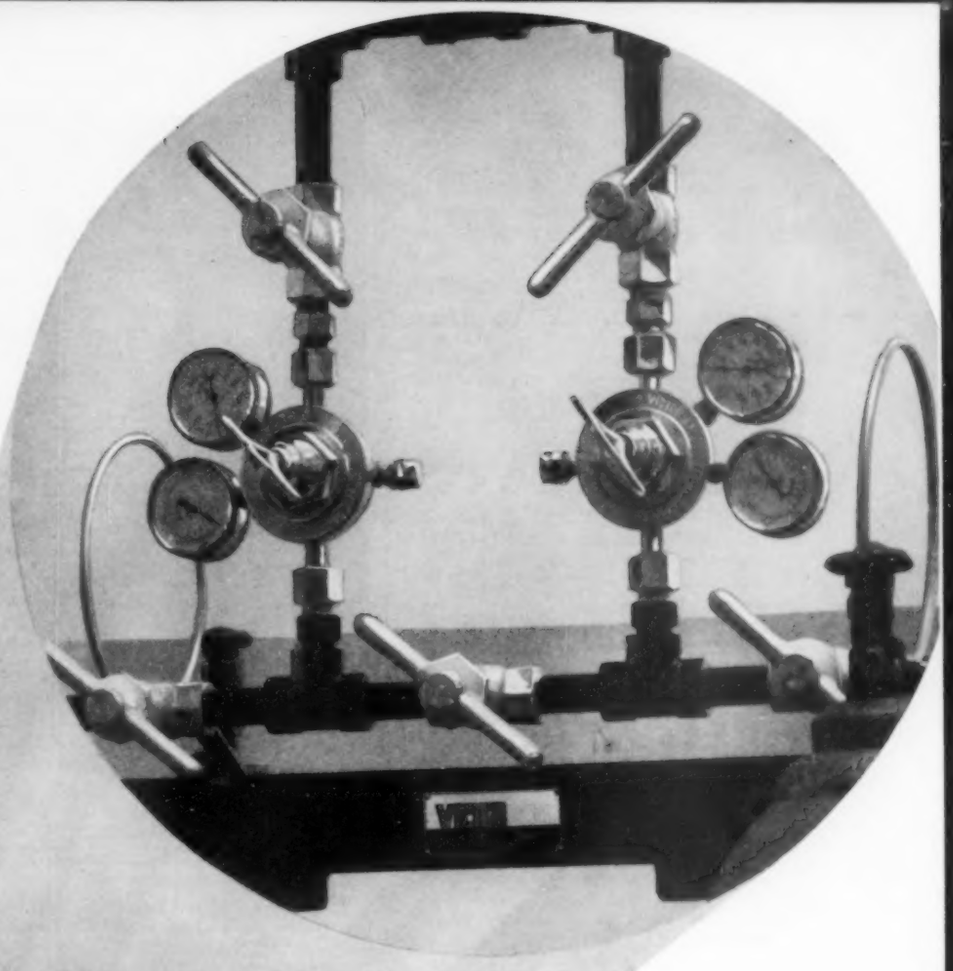

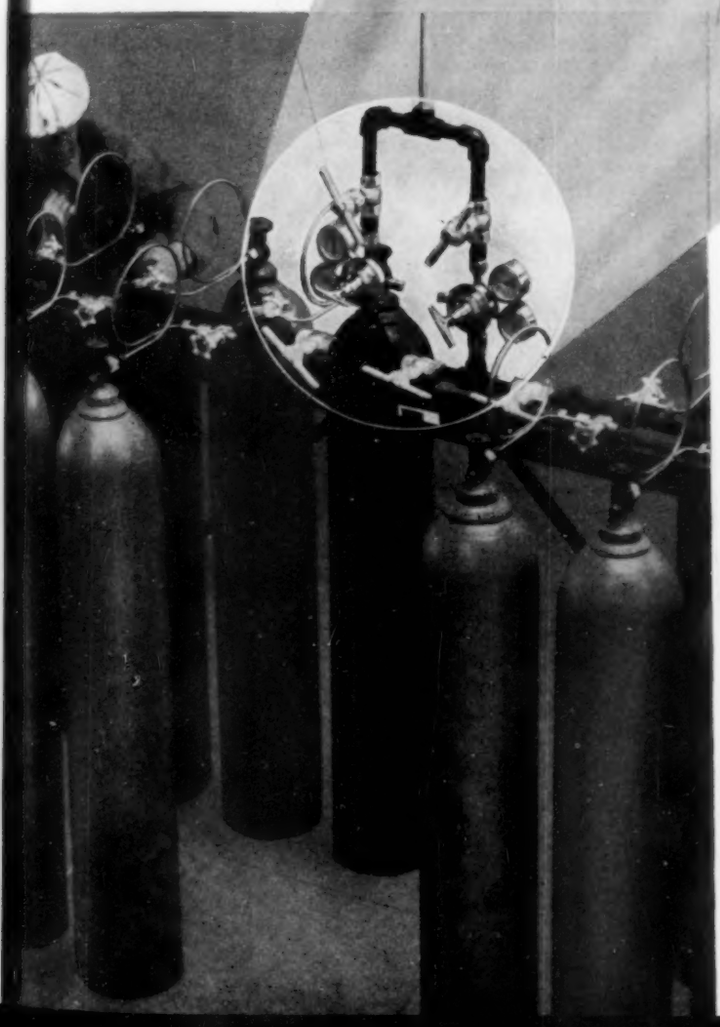

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gaged in spot welding of aluminum alloys.

This report was published by the AMERICAN WELDING SOCIETY, 33 West 39th St., New York, N. Y., in the form of a heavy paper covered pamphlet, 8½ x 11 in., 48 pages, illustrated, price $1.00.

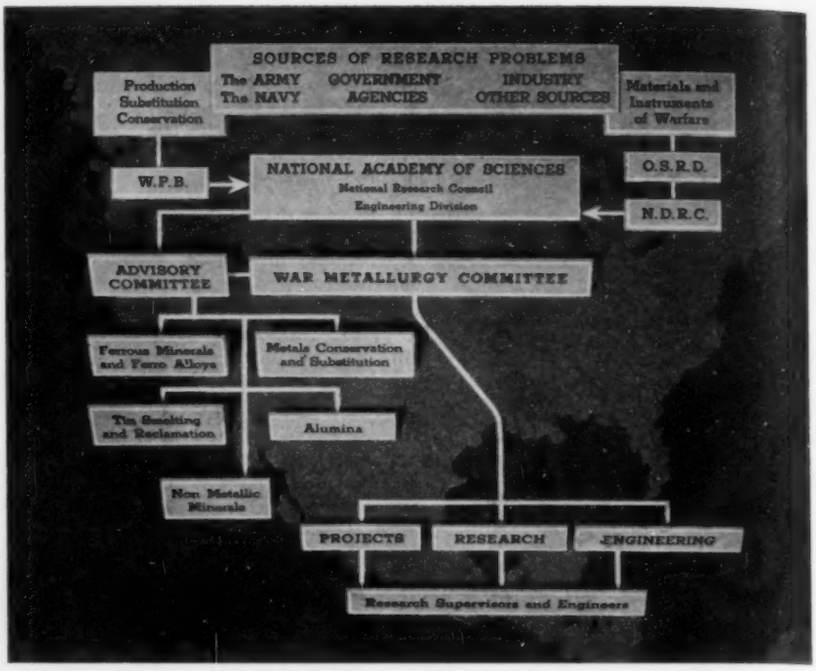
THE WAR METALLURGY COMMITTEE

The War Metallurgy Committee is an agency of the National Academy of Sciences and the National Research Council, charged with the conduct of metallurgical research for the War Production Board and the National Defense Research Committee of the Office of Scientific Research and Development.

The committee operates through three major sections: the first, formulating and placing research projects; the second, supervising the operation of these researches; and the third section correlating the committee's work with war metallurgical research of other government agencies, industrial and university research departments and with foreign research.

The Metals and Minerals Advisory Committee of the Academy serves both the War Production Board and the War Metallurgy Committee on problems involving production, substitution and conservation of strategic materials.

Clyde Williams, Director of Battelle Institute, Columbus, Ohio, is Chairman of both committees. Louis Jordan, National Academy of Sciences, Washington, is Executive Secretary.



TEN THOUSAND LABORATORY EXPERTS AND SCIENTISTS TO HANDLE WAR METALLURGICAL RESEARCH

How 125,000 Man Years of Research Experience and Confidential Laboratory Data Are Being Brought to Bear on the Problems of Metals for War

Frank B. Jewett, President of the National Academy of Sciences, announces the results of eighteen months' operation of the Academy's Metals and Minerals Advisory Committee and outlines work of the new War Metallurgy Committee.

The Metals and Minerals Advisory Committee for the past eighteen months,

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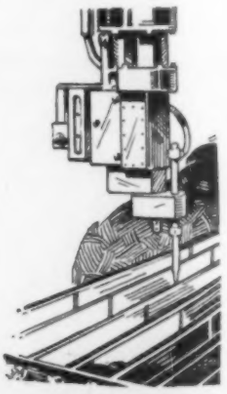

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In welding large manganese bronze castings, the physical properties and "hot ductility" of this electrode make it possible to arc weld without extensive pre-heating, and secure in the weld physical properties and corrosion resistance equal to that of the base metal.

In welding brass sheets or plates, the high tensile and yield strengths and good elongation of Ampco-Trode 10, provide welds that equal the physical properties of this wrought metal.

Ampco-Trode 10 coated weldrods may be used for metallic or carbon arc welding and for oxy-acetylene welding. They are made in 7 sizes—$\frac{1}{8}$" to $\frac{1}{2}$".

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according to Dr. Jewett, has furnished O.P.M. and W.P.B. with 113 reports. Fifty-three of these were on metals substitution and conservation; 47 on ferrous minerals and ferro-alloys; 4 on tin smelting and reclamation, and 9 on non-metallic minerals.

These reports, prepared by the various subcommittees of the Advisory Committee dealt principally with the problems arising from the necessity for allocation and substitution of materials, not only for general civilian uses, but even more particularly for war production processes and increased production of war materials.

The work of this Advisory Committee, according to Dr. Jewett, has been greatly enlarged since Pearl Harbor and is to be still further increased as it functions with and for the new War Metallurgy Committee. Clyde Williams, Director of Battelle Memorial Institute, Columbus, Ohio, and chairman of the Advisory Committee, is also Chairman of the new War Metallurgy Committee which has primarily been set up to appraise and conduct needed research work—for the army, the navy and other governmental departments as well as industry.

It is the function of this committee to collect data and information as requested by either the War Production Board or the Office of Scientific Research and Development, through its National Defense Research Committee, and to plan, present and supervise definite research projects for either war materials or armaments.

To Function as Nerve Center

The War Metallurgy Committee, and its Advisory Committee, according to Dr. Jewett, is set up to function as the nerve center for all metallurgical research organizations and departments in this country—since, depending upon the problem involved, the heads of any business, university or research organization can be counted upon by this Committee to make available the experience of their metallurgical scientists and engineers or their laboratory data.

Thus, this Committee makes available for the army and the navy, through either the War Production Board or the Office of Scientific Research and Development, the services of any or all metallurgical research, personnel and facilities. There are in excess of 10,000 such individuals in this country, and their combined experience represents well over 125,000 man years.

Saving Time, Mistakes and Money

One of the basic considerations in the operation of this Committee is that of the saving of time, the saving of mistakes and the saving of money. When the problem is proposed, through either the War Production Board or the Office of Scientific Research and Development, immediate action can be obtained by telephone communication with the leading scientists on that particular subject; initial Committee meetings are often held within twenty-four hours, and, if the request is urgent, within that same day a plan of procedure is laid down and submitted.

Furthering War-Winning Research

Every one in this country, and scientists and industrialists are no exception, is naturally anxious to contribute everything he can toward winning the war. New thoughts, new ideas, new short-cuts are constantly coming to the front. While it is not the place of the War Metallurgy Committee, according to Dr. Jewett, to be the repository for such suggestions and ideas, it recognizes as a very definite part of its wartime job, the appraisal of such of these problems and possibilities as are referred to it by the War Production Board or the Office of Scientific Research and Development.

English and Canadian Research

Another important function of the War Metallurgy Committee is to digest and make available to those properly interested through their participation in the war effort the results of both Canadian and English metallurgical research. Obviously both Canada and England have a great many of the same problems which confront us in this country and the interchange of information, through the proper channels, makes available to all the best thinking and practice of scientists and industrialists on both sides of the Atlantic.

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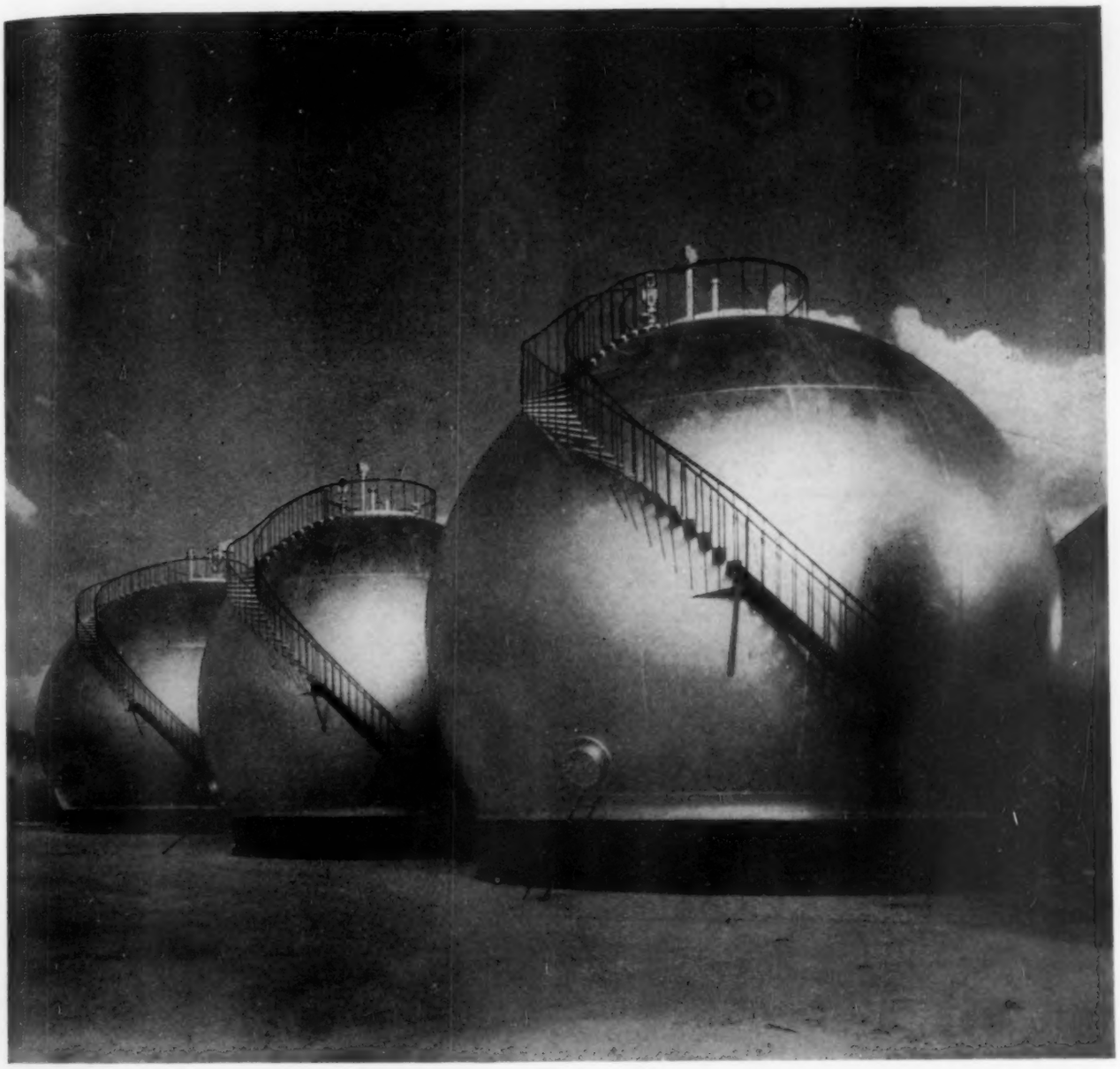

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Definite Research Projects

Typical of the problems referred to this Committee is one asking for improvement in welding processes. A subcommittee was immediately appointed, which collected all available known data from universities, engineering foundations and research departments of business organizations. The Project Section of the War Metallurgy Committee worked up the research indicated, research procedure, and, with the approval of National Defense Research Committee and the Office of Scientific Research and Development, this research was placed with one of the university laboratories and compensated for on a cost basis from funds made available by O.S.R.D.

The time involved in such research projects naturally varies. The report of the subcommittee, on many such projects, is made available within a matter of days, but the project itself may take anywhere from two to six months, stated Dr. Jewett, depending upon the nature of the research.

Typical of requests for data and projects from the War Production Board is that of the effect of substitution of lead-silver for tin-lead soldering of tin cans used for food products. Since tin is the one important metal which is not found in the United States, even in low-grade ores, it is obviously important that the conservation of the present use of tin is urgent.

Since a great proportion of the total consumption of tin is used in soldering, the substitution of lead-silver for tin-lead soldering is immediately dictated, but the problems involved, in certain canning processes, are such that definite research is needed before such substitution can be ordered.

This research project was prepared through the Project Section of the War Metallurgy Committee and will be administered through its research section, the work being done in one large university research laboratory, in cooperation with the National Canners Association.

Committee Membership

Indicative of the type of scientists and organizations represented, is the make-up of the War Metallurgy Committee and the Advisory Committee. The War Metallurgy Committee is composed of twenty-six members, as follows:

Clyde Williams, *Chairman*, Director, Battelle Memorial Institute, Columbus, Ohio

Zay Jeffries, *Vice-Chairman*, Director of Research, General Electric Company, Cleveland, Ohio

Louis Jordan, *Secretary*, National Academy of Sciences, Washington, D. C.

Carl Breer, Vice-President, Chrysler Corporation, Detroit, Mich.

Dr. Lyman J. Briggs, Director, U. S. Bureau of Standards, Washington, D. C.

Col. H. H. Zornig, Ordnance Department, Watertown Arsenal, Watertown, Mass.

James H. Critchett, Vice-President, Union Carbide & Carbon Research Labs., New York City

Col. R. S. A. Dougherty, Manager, Research & Development, Bethlehem Steel Company, Bethlehem, Pa.

Rudolph Furrer, Vice-President, A. O. Smith Corporation, Milwaukee, Wis.

Dr. H. W. Gillett, Chief Technical Adviser, Battelle Memorial Institute, Columbus, Ohio

S. D. Heron, Ethyl Gasoline Corporation, Detroit, Mich.

Dr. R. P. Heuer, Vice-President, General Refractories Company, Philadelphia, Pa.

Col. G. F. Jenks, Ordnance Department, Washington, D. C.

Dr. John Johnston, Director, Research Laboratory, U. S. Steel Corporation, Kearny, N. J.

Dr. Vsevolod N. Krivobok, Director of Research, Lockheed Aircraft Corporation, Burbank, Calif.

Frederick Laist, General Metallurgical Manager, Anaconda Copper Mining Company, New York City

Dr. W. K. Lewis, Head, Dept. Chemical Engineering, Mass. Institute of Technology, Cambridge, Mass.

Dean C. E. MacQuigg, College of Engineering, Ohio State University, Columbus, Ohio

C. E. McCuen, Vice-President, General Motors Corporation, Detroit, Mich.

Dr. Robert F. Mehl, Director, Metals Research Laboratory, Carnegie Institute of Technology, Pittsburgh, Pa.

Dr. Paul D. Merica, Vice-President, The International Nickel Co., Inc., New York City

Dr. Gilbert E. Seil, Technical Director, E. J. Lavino & Company, Norristown, Pa.

Captain Lybrand Smith, Office of Coordinator of Research & Development, Navy Department, Washington, D. C.

Dr. F. W. Willard, President, Nassau Smelting & Refining Company, New York City

Dr. Robert S. Williams, Head, Dept. of Metallurgy, Mass. Institute of Technology, Cambridge, Mass.

Col. A. E. White, University of Michigan, Ann Arbor, Mich.

ANNUAL MEETING AMERICAN SOCIETY FOR TESTING MATERIALS

That there has been little, if any, diminution in standardization and research work in engineering materials as carried out by the American Society for Testing Materials was evident from the heavy registration of members, committee members and guests at the Forty-Fifth Annual Meeting held at Atlantic City, June 22nd to 26th, the total figure reaching 1376 which does not include more than 200 ladies and others of the members' families. While this did not quite reach the Atlantic City figure of 1441 at the 1940 annual meeting and is below the figure for Chicago last year, it is an excellent attendance record, considering present conditions. Registration for the first two days, totaling 1095, was the highest of any year. Attendance at the various sessions and committee meetings was very good, the Symposium on Radiography, Session on Alternate Steels and the Round-Table Discussion on Water each having several hundred present.

While a number of the committees kept meetings at a minimum, there were still more than 200 throughout the week.

More than 55 new tentative standards were approved for publication as tentative and some 70 existing tentative specifications are to be referred to Society letter ballot for adoption as standard. This figure is frequently higher in Book of Standards' year (the combined Book of Standards will be issued in November of this year) but the tempo of adopting standards has increased in recent years and many more were adopted last year than in corresponding years. Including emergency specifications now totaling six, the Society will have in its 1942 Book of Standards some 1100 specifications, test methods and recommended practices. This figure compares with 667 in 1932 and 335 in 1922.

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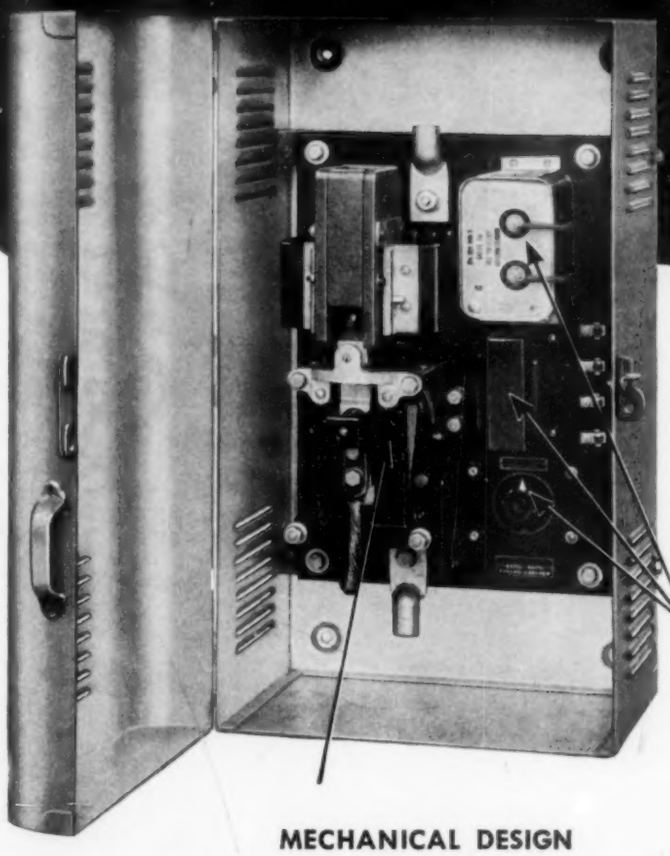


Elimination of arc heat at contacts makes derating unnecessary—and contact tip deterioration is greatly reduced. Adjustment is not critical and synchronization is stable.

Arcing is eliminated by separately energizing the magnet "shading" coil from the secondary of a small transformer.

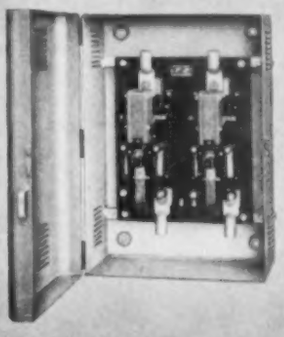
Correct rheostat adjustment causes contacts to part at instant when alternating current approaches zero—thus breaking the circuit when no current is flowing.

Condenser connected in parallel with the load overcomes normal tendency of arc to restrike after tips have parted.

MECHANICAL DESIGN

The primary circuit of a resistance welder transformer must be broken consistently and as often as 300 times per minute on some applications. Elimination of arcing improves contactor electrical performance, but mechanical design features are also important.

- Knife edge bearings require no lubrication and assure long mechanical life.
- Low inertia moving parts and short contact gap permit high speed operation.
- Large copper contact tips butt against solid supports, relieving studs of impact and conducting away heat.
- Shims, inserted behind stationary contact post, compensate for contact wear.



HIGH SPEED welder contactors

When operation is less frequent and loads are lighter, the *HIGH SPEED* contactor is well applied.

Both single and double pole types are available. Construction is similar to that of the *SYNCRO-BREAK* contactor, with synchronizing circuit omitted. A strong blowout coil quickly extinguishes the arc while a refractory arc chute confines it to a safe path.

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KOLLSMAN INSTRUMENT DIVISION, ELMHURST, NEW YORK

IN CANADA: SQUARE D COMPANY CANADA LIMITED, TORONTO, ONTARIO

NBC TO BROADCAST PROGRAM ON "THE ENGINEER AT WAR"

Beginning Thursday, July 16th, the National Broadcasting Company will broadcast from 6:30 to 6:45 P.M., over its nationwide network and possibly also by short wave a series of eleven radio programs dealing with the contributions of engineers to the prosecution of the war, according to an announcement made public today by Dr. R. L. Sackett, of The American Society of Mechanical Engineers, member of a committee representing the national engineering societies.

According to Dr. Sackett, the idea of telling the world by radio about engineers and their war activities came from a series of radio programs put on the air in 1941 by the American Institute of Electrical Engineers. The success of this series led the American Society of Civil Engineers, The American Institute of Mining Engineers, The American Society of Mechanical Engineers, The American Institute of Electrical Engineers and The American Institute of Chemical Engineers to appoint three representatives of each Society to form a committee to consider a possible program and report to each Society.

Dr. James Rowland Angell, Public Service Counsellor, National Broadcasting Corporation, was consulted and encouraged the committee to prepare a program which would reflect the varied contributions of engineers to the prosecution of the war program.

The committee began its deliberations before Pearl Harbor was attacked and had scripts under way on blackouts, bombs and damage to structures. The declaration of war, said Dr. Sackett, emphasized the importance of the proposed radio program. The National Broadcasting Company and the Office of Civilian Defense enthusiastically endorsed the committee's proposal and have been generous in their help and approval of scripts so far submitted. Controversial matters are included in the broadcasts and changes will be made when requested by OCD up to the minute that a program goes on the air. In this way the latest and authoritative information will be given.

The material has been prepared by eminent men or by those selected from their staffs because of special knowledge. The scripts have then been woven into a story which presents a few of the striking features of the part played by engineers in some of the more important fields.

The program is as follows:

July 16. Blackouts. Representative of OCD and Samuel G. Hibben, Westinghouse E. & M. Co.

July 23. Protection Against Incendiary Bombs and Gas. Sidney D. Kirkpatrick, President, Am. Inst. Chem. Engrs., and Dr. Arthur Ray.

July 30. The Resistance of Structures. Prof. H. E. Wessman, New York University; Walter D. Binger, Commissioner of Boro Works, Manhattan.

August 6. The Navy. Ships. Admiral S. M. Robinson.

August 13. Dry Docks and Ship Repair Bases. Rear Admiral Ben Moreell.

August 20. Tanks and Tools, prepared by Chrysler Corporation.

August 27. Airplanes, prepared by Wright Aeronautical Corp.

Sept. 3. Petroleum Production. Prepared by Robert E. Wilson, Pres., Pan American Petroleum Company.

Sept. 10. Power, -Hydro, Steam Electric. Glen B. Warren, General Elec. Co., and others.

Sept. 17. U. S. Engineers Corps in Peace and War.

Sept. 24. Communications in Action.

SYMPOSIUM ON RADIOGRAPHY OUTSTANDING FEATURE AT A.S.T.M. ANNUAL MEETING

Unquestionably the outstanding feature of the Forty-fifth A.S.T.M. Annual Meeting was the Symposium on Radiography comprising 13 technical papers presented in three sessions. Arranged by Committee E-7 on Radiographic Testing, headed by H. H. Lester, Watertown Arsenal, the symposium when published will acquaint the engineering profession with the most recent developments in X-ray and radium radiography of engineering materials. Since 1936 when the Society held its first symposium on this subject resulting in a 350-page publication, the first of its kind in the English language, there have been phenomenal increases in applied voltage, more extended use of radium, and a much wider diversification of products investigated by these testing methods.

In the discussion of radiography of welds and weldments, it was indicated that much of the present-day production speed has resulted from welding, which in turn has greatly increased the number of radiographic testing units in use not only in the pressure vessel field but for spot checks in other structural welds. Similarly, the field of gamma-ray radiography is expanding. Also explained were some of the advantages of the million volt X-ray unit.

VICTOR CATALOGUE

With the American output of airplanes, ships and munitions of war depending largely on welding, Victor Equipment Company of San Francisco issued a handsome 64-page catalogue which tells how its flame-cutting and welding apparatus is speeding up industrial production from Coast to Coast.

"Mindful of the Government's plea to conserve man power and tires, ordinarily required by salesmen," said E. L. Mathy, Vice-President, "we have produced the largest and most comprehensive catalogue in twenty years to make our approach to industry. The book, profusely illustrated, is designed to assist the manufacturer in making a wise selection of gas welding and cutting equipment."

Outstanding color work in the catalogue dramatizes the use and construction of Victor equipment in a manner seldom found in technical publications. Hundreds of vital parts of the apparatus are spread across richly colored blue, green, gold and brown backgrounds. These are accompanied by scores of black and white reproductions of parts and equipment. The untouched photographs and the accompanying technical material, taken together, form a handbook on welding and cutting for service workers and engineers.

The book is being distributed to industrial concerns, engineers and technical libraries throughout the United States.

CORROSION AND FATIGUE EVALUATION OF METALS

Several technical papers in the session of the A.S.T.M. annual meeting, devoted to corrosion and fatigue are of distinct interest to designers and others concerned with the evaluation of metals. Fatigue tests were described for evaluating corrosion damage of certain metals, which is part of the work being carried on for sheet metal used in aircraft. Flexural fatigue tests determined the fatigue limits on stainless steel sheet specimens before and after prolonged exposure in marine environments. The rate of corrosion was relatively rapid during the initial stages of exposure, but thereafter a near arrest in the attack occurred. Panels exposed to the marine atmosphere suffered more damage, for the same period of exposure, than those which were wet periodically by tidewater. The method permitted a reliable evaluation of the damage resulting from corrosion.

Another contribution covered the evaluation of fatigue damage of steel by supplementary tension-impact tests. This work on fatigue damage is very important

ELECTROLOY ALLOYS for RESISTANCE WELDING ELECTRODES and DIES

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Seam
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ELECTROLOY ALLOYS were developed specifically for the resistance welding industry. ELECTROLOY ALLOYS cover the full range of physical properties necessary to the manufacturers and users of resistance welding equipment.

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New **HOLLUP A.C. ARC WELDERS NOW READY FOR WAR WORK!**

Giving You . . .

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6. No Magnetic Field Loss

New bulletin giving full descriptions and specifications of these new Hollup A. C. Welders sent free upon request.

Hollup Instruction Manual for A. C. and D. C. Welding. A 125 page illustrated book that includes 16 complete lessons and detailed procedures for all Hollup Electrodes. Sent postpaid upon receipt of 50c for each manual ordered.

UTILITY MODELS
Low cost Welders for the small shops. 16 heat changes . . . fiberglass insulation . . . Underwriters' Laboratories Approved.

HEAVY-DUTY
INDUSTRIAL MODELS
Available in 300-400-500 and 600 amp. sizes.

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Available in 150-200-250 and 275 amp. sizes.

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since many service failures in load-bearing members are due to fatigue. The authors pointed out that aircraft are particularly vulnerable in the sense that failure without warning of a working part in flight may result in the total loss of plane and occupants. No appreciable loss in tension-impact resistance or elongation during impact resulting from prior repeated overstress in fatigue was noted in Haigh axial-loading specimens in the pre-crack stage except for cases where the mean tensile stress and stress amplitude were high enough to cause permanent sets of more than 0.01 in. during fatigue stressing. Such conditions are improbable in service and would be easily detected. With the formation of fatigue cracks, however, the situation was changed. Even the smallest detectable fatigue cracks were usually accompanied by substantial losses in tension-impact resistance. An adverse low-temperature effect (−33 C.) required the presence of a fatigue crack of easily detectable size; therefore, no adverse low-temperature effect may be expected as a result stress in the pre-crack stage of fatigue.

D. J. McAdam, Jr., National Bureau of Standards, presented another in his series of papers covering the influence of the combination of principal stresses in fatigue of metals, in which he stated again the evidence that cohesive strength of a metal cannot be represented by a single stress value, but comprises an infinite number of values depending on the combination of the principal stresses.

The annual report of Committee A-5 on Corrosion of Iron and Steel which has sponsored so many important research investigations in its 36 years of existence again tabulated the record of failure in the copper and copper bearing material exposed at Annapolis since 1916, with semi-annual inspection from that time on through 1942. The data continued to demonstrate the efficacy of copper in reducing failures due to atmospheric exposure. Another part of the report discussed results of inspection and failure on galvanized corrugated sheets.

Appended to the annual report of the Research Committee on Fatigue of Metals was a report by Prof. H. F. Moore and an associate, covering the effect of size of specimen on fatigue of three types of steel, two carbon grades and a chromium-molybdenum type. Five different size specimens were tested as cut from 3 or $3^1/_2$ in. in diameter bars. The results showed a maximum size effect of about 30 per cent of the endurance limit for 2 in. specimens of the S.A.E. 1020 steel. There was a tendency for the endurance limit to become constant for specimens of $^1/_2$ in. minimum diameter and larger.

STEEL AT A.S.T.M. ANNUAL MEETING

Notable in the A.S.T.M. session devoted to steel was the report of Committee A-1 as presented by Normal L. Mochel, chairman, also the paper discussing the comparative quality of converter cast steel. Many important recommendations were acted on as recommended by the Society's Committee on Steel. Particularly important were those in the field of pipe and tubing where a new method of determining elongation values based on pipe wall thickness is being established in two of the country's most basic specifications for welded and seamless steel pipe (A 53) and for lap-welded and seamless steel pipe for high-temperature service (A 106). Also incorporated in these standards is a new method of determining flattening test requirements by means of a formula which establishes more rational values based on pipe sizes and grades. These two specifications will also permit the use of acid bessemer seamless material and the electric resistance welding process. Two new pipe specifications were approved at the annual meeting, one covering copper-brazed tubing suitable for general engineering uses, particularly in the automotive, refrigerator and stove industries for fuel lines, oil lines and so forth. The second specification covered welded alloy open-hearth iron pipe which is made from a highly refined iron produced in the basic open-hearth or electric furnace with which is alloyed in a solid solution a minimum of 0.40 per cent copper and 0.05 per cent molybdenum.

SALVAGING TOOLS

As a contribution to the war effort following the lines of the War Production Board, Eutectic Welding Alloys, Inc. of 40 Worth St., New York, N. Y. has printed a special folder covering the subject of salvaging tools and machine parts which is one of the biggest bottlenecks in today's production.

LINCOLN ELECTRIC GIVES SERVICE PINS TO VETERAN EMPLOYEES

Among the 206 veteran employees whose tenure of service ranges from 10 to 35 years the following members of the SOCIETY received awards on Wednesday, July 1st:

James F. Lincoln, president and general manager, period of service over 35 years.

J. C. Lincoln, chairman of the board and treasurer, period of service over 35 years.

A. F. Davis, vice-president and secretary, period of service 25 years.

C. M. Taylor, vice-president and sales manager, period of service 25 years.

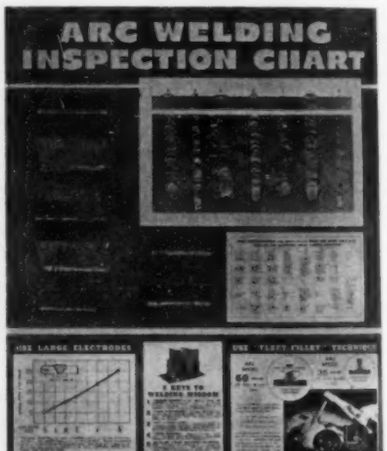
There were 26 employees in the 20-year group; 66 in the 15-year and 103 in the 10-year.

SILVER ALLOY BRAZING OF FABRICATED COPPER PIPING

A very interesting paper has been prepared by J. C. Powers, Jr., and H. DeM. Lucas of Handy & Harman, 82 Fulton St., New York, giving a comprehensive treatment of silver alloy brazing of fabricated copper piping. The brazing of fabricated copper piping with silver alloys presents very few problems and can be successfully accomplished by inexperienced men, having as little as a week to ten days' intensive training.

WELD INSPECTION CHART

An arc welding inspection chart, which will provide welding inspectors and others concerned with weld production a simple and extremely helpful aid for use in inspecting welds, has just been published by The Lincoln Electric Company, Cleveland, Ohio.



The chart (see illustration) presents very graphically the different types of welds obtained when the work is done normally, with normal current, voltage and speed, as compared with those obtained when these factors are not normal.

The chart is available free of charge to inspectors of welding and others concerned with welding.

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This new low temperature method has revolutionized welding. It binds without melting the base metal. This means high strength . . . matching color. It means less stresses . . . less warping . . . less preheating.

Try this modern welding method in your shop. The results will amaze you.

Welds: Cast Iron, Iron, Nickel, Steel, Aluminum, Bronze, Copper, Brass, Magnesium, etc.

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DIFFRACTION

and

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TODAY, when industry is facing the problems resulting from conversion, faster production, greater accuracy, elimination of waste, and replacement of critical materials, X-ray inspection is providing many of the answers.

The Kelley-Koett Mfg. Co.—pioneer creators of quality X-ray apparatus since 1900—has developed this new combination to meet industry's urgent need.

This unit provides; conventional radiography for the inspection of castings and welds; microradiography for investigation of alloy compositions and other materials; X-ray diffraction analysis for the laboratory study of crystalline structures

Portable and compact it can be moved anywhere in the plant and used inside fabricated assemblies. It is easily adaptable for stationary or assembly line inspection or research work in the laboratory, and supplies industry with a long wanted X-ray inspection tool of wide application. For more detailed information consult Keleket X-ray engineers.

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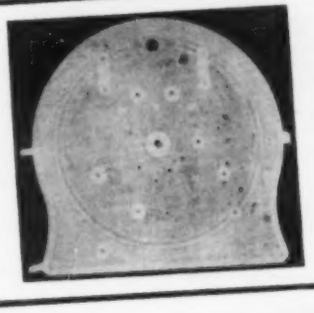
RADIOGRAPHS *made with this unit!*

SPOT-WELDED ALUMINUM SHEET

This is a radiograph of a spot-welded aluminum sheet used in fabrication of aeroplanes. Note how clearly the star shaped cracks, in the center of the spot welds are revealed. This is cause for rejection—yet would have not been detected except by X-ray inspection.



ALUMINUM DIE CASTING

The aluminum die casting, from all outward appearances, was perfect. Only by X-ray inspection could the extreme porosity be detected as shown by the radiograph

HALF-INCH BRONZE PLATE

The weld in this half-inch thick bronze plate shows perfect on the surface and is nearly perfect clear through, except for some porosity which shows up on the radiograph after X-ray inspection

COMBINATION INDUSTRIAL UNIT

PIONEER CREATORS OF *QUALITY* X-RAY EQUIPMENT SINCE 1900

Photo courtesy Alco Products

WELDED PRESSURE VESSEL

The view shown above is a vessel 82 ft. long and approximately 10 ft. 3 in. inside diameter, fabricated of $^{15}/_{16}$ in. thick steel with $1^{1}/_{16}$ in. thick heads. The total weight is approximately 122,000 lb. The vessel is stress relieved but not X-rayed. This vessel will be used as a propane storage tank and consequently was designed for approximately 210-lb. working pressure.

TRAILERS

Arc welding has made the huge 75-ton trailer, pictured below, a practical means for hauling heavy machinery—even over rough terrain. Although it weighs only $19^{3}/_{4}$ tons, the trailer is capable of carrying a heavier load than the average railroad freight car.

If Le Tourneau engineers had chosen to cast the trailer parts, the cost for this process would have rendered the job impractical. Arc-welded construction, however, permitted maximum flexibility and strength, low cost and light weight.

The trailer measures 30 ft. long, 14 ft. wide and requires 24 x 30 tires equipped with air brakes. The Tournapull fastened to the trailer is also of welded construction. Both units complete weigh $42^{1}/_{2}$ tons.

Photo courtesy Hobart Brothers Co., Troy, Ohio

EXCAVATORS

By using alternating-current welders in fabricating excavators and heavy duty trailers, the Hanson Clutch and Machinery Company of Tiffin, Ohio, is getting good penetration as well as speedy, neat welding at reduced costs. By correct positioning, this company is able to weld small and large parts alike with their 300-ampere a-c arc welders.

Photo courtesy General Electric Co

The photograph shows an upper turret bed for a power shovel being fabricated with an a-c welder shielded arc electrode.

WELDING HANDBOOK NOW ON SALE

1600 pages of up-to-date useful information. Prepared by 270 experts.

Price $6.00 to Non-Members U. S. A. $5.00 to Members.

Buy "Proven Fluxes" with Years of Guaranteed Satisfaction behind them

The Trade-Name is "ANTI-BORAX"

Ask for Them ***Unequalled for Quality***

A Flux for every metal: Cast Iron Welding Flux No. 1; Brazing Flux No. 2; Braz-Cast Flux No. 4, for bronze-welding cast iron; "ABC" Aluminum Flux No. 8 for sheet Aluminum and all alloys of Aluminum; Stainless Steel Flux No. 9; Silver Solder Brazing Flux No. 10; "Anti-Borax" Tinning Compound No. 11.

ANTI-BORAX COMPOUND COMPANY
Fort Wayne, Indiana

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*Full Page	$100	$90	$80	$70
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*Inside Preferred	115	105	95	85

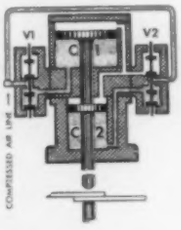
***10% Extra for bleed full pages. Color $40 Extra per color added.**

SOUNDER, MORE UNIFORM SPOT WELDS IN ALUMINUM ALLOYS!

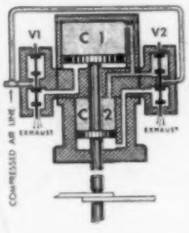
SCIAKY VARIABLE PRESSURE CYCLE

How it Operates

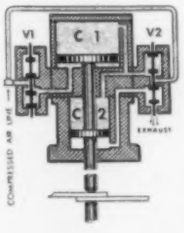
The variation of electrode pressure in the Sciaky Welding Process is effected by two air cylinders of different cross sectional areas (C-1 and C-2), mounted on upper arm of machine. Dual electro-valves (V-1 and V-2) control their action. Duration of each stage in the cycle is governed by precision electric controls.



1. REST POSITION. Electrode retracted. Both electro-valves are de-energized which permits air pressure to be exerted on the under side of pistons in both cylinders, thus lifting the electrodes.

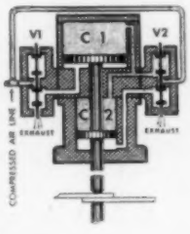


2. PRE-COMPRESSION. Both electro-valves are energized, admitting air pressure to the top of the pistons in both cylinders, thereby forcing the electrode downward with maximum pressure.

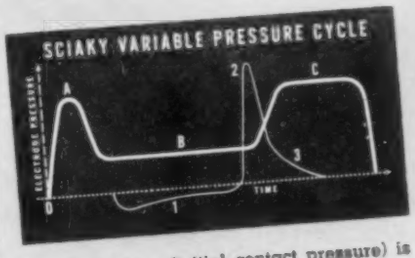


3. WELDING PRESSURE. Left electro-valve is de-energized. Pressure is maintained on top of piston in lower (smaller) cylinder, while air is admitted to under side of piston in upper cylinder. This neutralizes the downward pressure in the upper cylinder, and reduces the effective electrode pressure to about one-third of maximum.

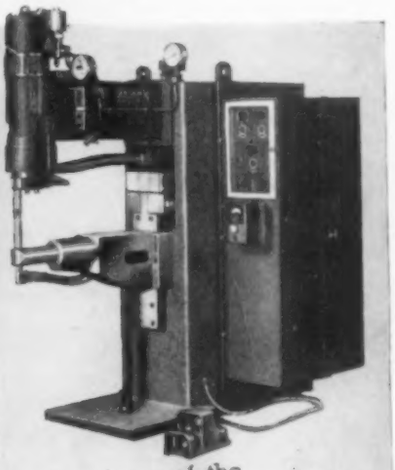
4. RECOMPRESSION. Both electro-valves are again energized. The neutralizing (upward air pressure) on under side of piston in upper cylinder is exhausted almost instantaneously, restoring the electrode pressure to maximum —the same value as during pre-compression.



SCIAKY* WELDING PROCESS "FORGES" THE METAL AFTER THE WELD....



Precompression (initial contact pressure) is indicated at A. Welding (reduced) pressure at B, and Recompression (forging pressure) at C. Electrical current is indicated by light line. During storage of energy period (1) the metal is preheated. The surge of current to maximum (2) effects the weld, and decays, (3) following the exponential curve.



Type PMCO2S-16 Sciaky Stored Energy Electric Resistance Spot Welder

In spot welding any metal, the inner surfaces of the pieces being joined are converted from a solid to a molten state at the point of passage of the welding current. This conversion in aluminum and its alloys requires a very high temperature which results in expansion of the metal in the molten zone.

The subsequent cooling of this zone is extremely rapid because of the high thermal conductivity of aluminum, and also because the artificial cooling of the copper electrodes with which the aluminum at high temperatures would otherwise tend to alloy. This rapid cooling causes sudden contraction of the weld nugget and the consequent cracks and internal stresses tend to weaken the weld.

The Sciaky Process embodies exclusive features to compensate for these undesirable conditions. In addition to pre-heating, which offsets the high thermal conductivity of aluminum and in consequence slows down the cooling process, Sciaky provides the added protection of a "forging" pressure to offset the metal shrinkage. Thus the Variable Pressure Cycle combines with the Stored Energy Principle and the exclusive pre-heating feature to insure welds of sound metallurgical quality.

As a result, the Sciaky Welding Process is preferred by practically all major manufacturers of air craft.

SCIAKY BROS.

Manufacturers of a Complete Line of D-C and A-C Electric Resistance Welding Machines

4915 West 67th Street, Chicago, Illinois

*Pronounced See-ack-ee

SCIAKY PROCESS ELECTRIC RESISTANCE WELDING
STORED ENERGY • VARIABLE PRESSURE

NEW PRODUCTS

The Society assumes no responsibility for the validity of claims in this Section

NEW WELDING AND BRAZING FLUXES

A new line of welding fluxes for both ferrous and non-ferrous metals which have had the benefit of intense laboratory research and have been exhaustively field-tested on jobs of all types, has just been released for marketing by the National Cylinder Gas Company of Chicago.

National No. 1 is a flux for welding cast iron. It floats to the surface the heavy oxides which form during welding and keeps them liquid so that a dense, non-porous and ductile weld can be produced.

National No. 2 is a cast-iron brazing flux which produces a good bond at low base temperature and holds the bronze being applied at a uniform molten consistency.

National No. 3 brazing flux, suitable for brass, bronze, copper, steel and malleable iron, is so compounded that it reduces atmospheric oxidation and keeps flux glaze at a minimum so that the bronze deposit remains clean and bright. Thorough tinning and cleaning is promoted through the ability of the flux to run well ahead of the weld puddle.

National No. 22 is an aluminum flux for sheet, cast, wrought and alloys. The fluxing action is fast and effective as it floats out oxides and impurities which form during welding.

On this entire line of fluxes, precautions have been taken to reduce noxious fumes, bubbling and boiling. Another feature of all types is their ability to adhere to hot rods in the proper proportion with reduced tendency to blow away. These fluxes are packed in wide-mouth, non-tipping containers.

A new bulletin fully describing the National line of fluxes is available upon request.

HEAVY-DUTY WELDING POSITIONER

Announcement of the addition of a 20-ton capacity heavy-duty unit to its line of standard Welding Positioners has been made by the Industrial Division, Ransome Concrete Machinery Company, Dunellen, N. J.

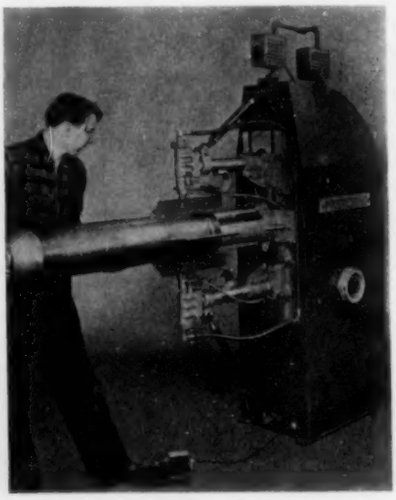
The machine will handle a maximum load of 22½ tons with a center of gravity up to 12 in. above the table top, tilting it to any position through a range of 45° from horizontal in one direction to a vertical position in the other, and will rotate a similar load with an eccentricity of 12 in. from center of the table top.

The 84-in. square steel table top is machined, reinforced by ribs on the under side and provided with 4 radial and 4 longitudinal T-slots for readily attaching the work to the table surface. The heavy base frame is of all-welded construction for maximum strength with minimum weight. The table rotates a full 360° at a speed of ⅓ r.p.m. in either direction and is controlled through a remote push button control station. The two tilting gear segments provide a means for tilting the load uniformly even when an unbalanced load is being handled. Tilting and rotating may be accomplished simultaneously as separate driving motors are provided. V-belt drive between motors and gear reduction units are used because of their ability to absorb shock loads due to sudden change from forward to reverse operation. Table top spindle shaft turns in two Timken bearings for permanent alignment of mechanism. Timken bearings are also used at other vital points in the machine.

Full information may be secured by writing the manufacturer.

STITCHING FINS TO FLARES

Housings for the army's giant parachute flares now have their fins "stitched" on by rows of spot welds, as shown in the accompanying photograph. The machine consists of a Standard Progressive pedestal welder equipped with two guns, an upper and a lower, instead of the usual single gun. The center electrode is fixed and serves as a mandrel for guiding the housing. The locating fixture for keeping the fins correctly aligned was removed, here, to show the guns, etc. The operator merely pushes the housing along, between welds, the machine automatically repeating the welding operation as long as the foot switch is depressed. Both guns weld simultaneously, only one timer therefore being required. The machine, however, is equipped with two pressure interlocking pressure switches to make sure that one gun does not weld without the other one. About 18 welds are required for each pair of fins welded simultaneously, or a total of 36 welds for each housing. Note that the end ring is also spot welded to the main housing, using the same machine.



WELDING LOCOMOTIVE

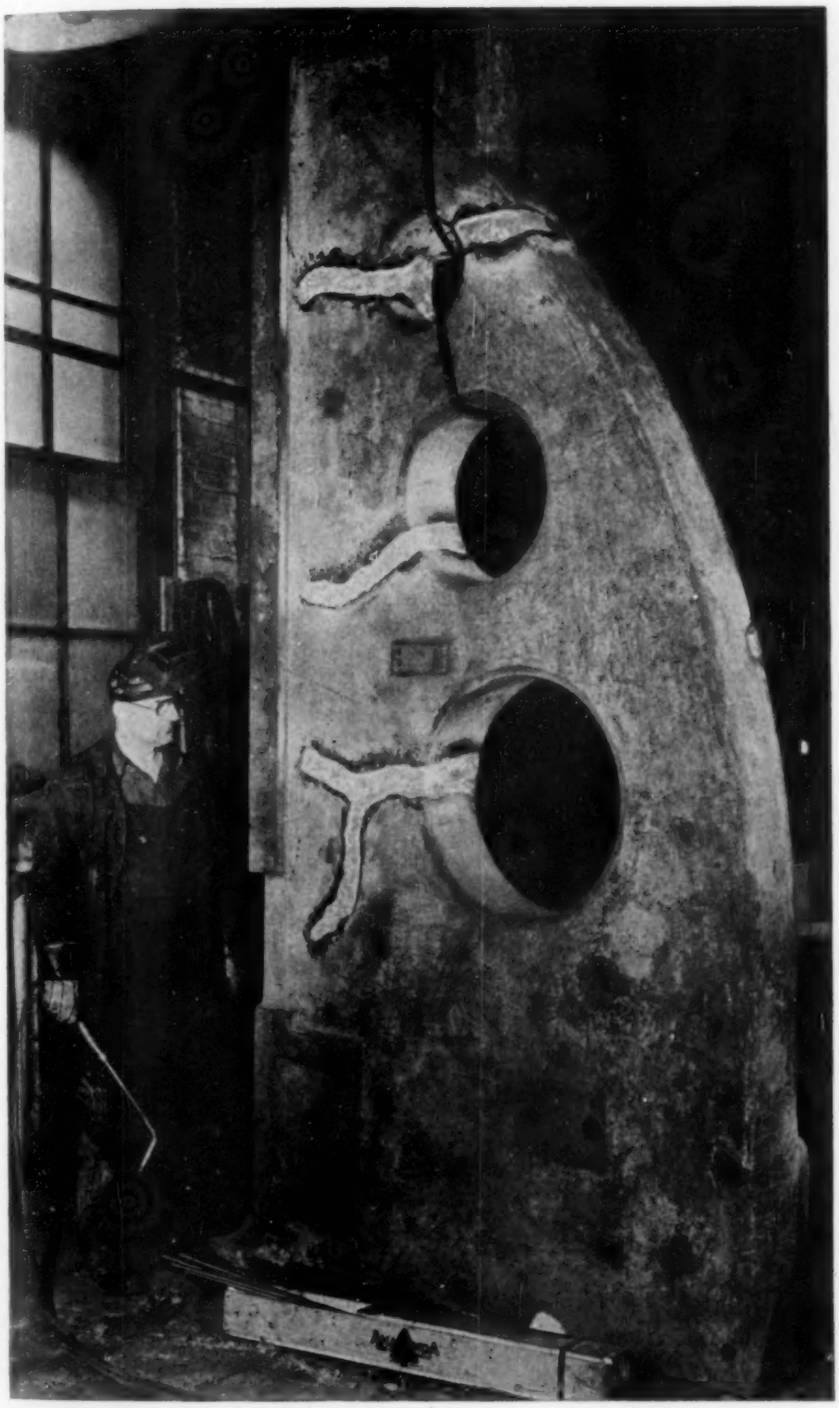
The view above shows welding outer steel sheets to the framing of the hood of a General Motors Diesel main line passenger locomotive at the plant of the Electro-Motive Corporation at La Grange, Ill.

NEW SEPARABLE COUPLER

Among the latest Burndy developments is the Hyclasp, a separable coupler (also known as a jack knife connector) for wires and cables, providing a quick and positive method of making or breaking the circuit—particularly useful for welding cables and wherever equipment must be periodically disconnected for inspection or testing.

All Clasp connectors feature constant contact pressure, self-cleaning contacts and interchangeable parts (for same size conductors), and can be supplied with insulating shrouds when desired. Complete specifications will be found in the new Burndy Marine Catalog, No. M-42, Burndy Engineering Co., Inc., 459 East 133rd St., New York, N. Y.

Saved: month's loss on A-1-a orders



2-ton Section of 100" Boring Mill Goes Back on Job After Speedy "997" Repair Weld —Only 39 Man Hours for Chipping, Grinding and Welding

Score another production victory for repair welding. This huge section for a boring mill working exclusively on A-1-a priority business was "down" for an unusually short time, despite its severe damage.

The Hebeler Welding Company of Buffalo, repair welding specialists, provided the way to give our war program the use of this mill with a minimum delay . . . repair welding with Anaconda 997 Low Fuming Rod.

75 pounds of this bronze welding rod were used, 600 feet of air and gas were consumed and 39 man hours required for the chipping and welding which put the mill in shape for active service.

For vital jobs like this one, Anaconda 997 Low Fuming Welding Rod, Tobin Bronze and other Anaconda Welding Rods are always "on call". 4294

The trade-marks "Anaconda" and "Tobin Bronze" are registered in the U. S. Patent Office.

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List of New Members

June 1 to June 30, 1942

BOSTON

Carver, Allen F. (B), 869 Washington St., Newtonville, Mass.
Dufort, Jules G. (B), N. E. School of Prac. Training, 11-13 Central St., Manchester, N. H.
Rosenthal, Daniel (C), Mass. Inst. of Tech., Cambridge, Mass.

CANADA

Somerville, William C. (D), 305—2nd St., New Westminster, B. C.

CANAL ZONE

Lebsack, Reuben D. (C), P. O. Box 579, Diablo Hts., Canal Zone.
Low, William H. (C), P.O. Box 321, Balbao, Canal Zone.

CHICAGO

Campbell, G. E. (B), Pettibone-Mulliken Corp., 4710 W. Division, Chicago, Ill.
Newcom, Harlen W. (B), 9919 So. Aberdeen St., Chicago, Ill.

CINCINNATI

Broughton, Robert (D), 116 Mulberry St., Cincinnati, Ohio.
Rowell, W. Henry (C), Kenton County Voc. School, 3rd & Court Sts., Covington, Ky.
Williams, Glyn O. (B), 22 W. Franklin, Troy, Ohio.

CLEVELAND

Blasius, Peter F. (D), 890 E. 141 St., Cleveland, Ohio.
Carin, Steve (C), 152 Cleveland St., Elyria, Ohio.
Geer, W. H. (C), 13009 Broadway Ave., Cleveland, Ohio.
Harter, Isaac (B), Babcock & Wilcox Co., Barberton, Ohio.
Henrickson, Chester (C), G. A. Henrickson Co., W. 3rd & Jefferson, Cleveland, Ohio.
Vargo, E. H. (B), Vargo Welding & Engrg. Co., 7301 Grand Ave., Cleveland, Ohio.
Wager, Francis W. (C), R. D. 3, W. Jackson St., Painesville, Ohio.

COLORADO

Lambrecht, Steve (D), 3130 Humboldt St., Denver, Colo.
Rosenbach, Jake (D), 3606 Delgany St., Denver, Colo.
Rosenbach, Joseph G. (D), 3550 Humboldt St., Denver, Colo.
Ziegler, Alex (D), 3434 Humboldt St., Denver, Colo.

DETROIT

Donaldson, C. H. (C), Ford & Beck Rds., Rt. 1, Plymouth, Mich.
Good, Adelbert C. (B), Wayne University, Detroit, Mich.
Platz, Henry T. (B), 12551 Flanders Ave., Detroit, Mich.
Taylor, Earl A. (A), Hudson Motor Car Co., 12601 E. Jefferson, Detroit, Mich.

INDIANA

Abernathy, Paul H. (D), R.R. 5, Anderson, Ind.
Hexamer, George B. (D), 1533 Noble St., Anderson, Ind.
Holder, Charles D. (D), Daleville, Ind.
Hook, Archie M. (D), R.R. 3, Alexandria, Ind.
Mercer, David J. (D), R. 3, Pendleton, Ind.
Shreyes, Harry A. (D), 2128 Central Ave., Anderson, Ind.

KANSAS CITY

Sweeney, E. J. (B), Sweeney Trade Schools, Inc., 1624 Grand Ave., Kansas City, Mo.

LOS ANGELES

Bladholm, E. F. (C), 827 Malcolm St., Los Angeles, Calif.
Clausen, Francis F. (C), Sherman Institute, Riverside, Calif.
Coleman, John R., Jr. (D), Victor Equip. Co., 3821 S. Santa Fe Ave., Los Angeles, Calif.
Davies, Robert U. (D), 828 W. 23rd St., San Pedro, Calif.
Davis, W. L. (D), 313—14th St., Box 56, Seal Beach, Calif.
Erwin, Fred G. (C), 3643 E. 54th St., Maywood, Calif.
Fiske, John J. (B), 1327 Stratford Ave., South Pasadena, Calif.
Ganahl, Lawrence E. (D), 230 So. Beechwood Dr., Burbank, Calif.
Grant, E. G. (C), 556 Ala Vista Ave., So. Pasadena, Calif.
Martin, James N. (D), 2150 Parneli Way, Altadena, Calif
Quinn, Vincent A. (D), 13007 Dickens, No. Hollywood, Calif.
Strout, Gus (D), 1798 N. Grand Oaks, Altadena, Calif.

MARYLAND

Bendak, Frank J. (C), 906 Bonaparte Ave., Baltimore, Md.
Dorff, Arlo (D), Bethlehem Shipbldg. Co., Sparrows Point, Md.
Greene, William R. (D), 631 Havey St., Baltimore, Md.
McFarland, John (D), 617 S. Lakewood Ave., Baltimore, Md.
Montaigne, Howard R. (C), Harris Calorific Sales Co., 209 Key Highway, Baltimore, Md.
Spagnoli, Herbert J. (D), 3812 Hudson St., Baltimore, Md.
Vardavas, John (D), 735 So. Oldham St., Baltimore, Md.

MILWAUKEE

Von Rohr, E. Jeane (C), 2540 N. Palmer St., Milwaukee, Wisc.

NEW YORK

Destefanis, Ralph (D), 519 Coney Island Ave., Brooklyn, N. Y.
Gay, Philip D. (D), Suffolk Welding Supply Co., 45 Culver Hill, Southampton, L. I., N. Y.
Gordis, Philip (B), 170 Bleecker St., New York, N. Y.
Stapleton, Joseph A. (B), 420—82nd St., Brooklyn, N. Y.
Zenthen, Albert W. (F), 230—75th St., Brooklyn, N. Y.

NORTHERN NEW JERSEY

Palmer, Walter (B), Hollup Corp., 2136—85th St., North Bergen, N. J.
Rolf, William E. (D), 92 No. Essex Ave., Orange, N. J.

NORTHERN NEW YORK

Doty, W. D'Orville (F), 2209—16th St., Troy, N. Y.
Kubas, Joseph J. (D), 100 Forbes St., Amsterdam, N. Y.
Lampman, Paul L. (D), American Locomotive Co., Schenectady, N. Y.
Nardi, Arthur (D), 1350 Parkwood Blvd., Schenectady, N. Y.
Palmer, Harry L. (C), 1113 Garuer Ave., Schenectady, N. Y.

NORTHWEST

Anderson, Kenneth (C), St. Paul Vocational School, 14th & Jackson St., St. Paul, Minn.

PHILADELPHIA

Iannetti, Armand (D), 2644 Gerritt St., Philadelphia, Pa.
Lamborn, Samuel W. (B), Somerton, Philadelphia, Pa.
Pister, Charles (D), 6105 Elmwood Ave., W. Philadelphia, Pa.

PITTSBURGH

Brown, Albert A. (B), H. H. Robertson Co., 2400 Farmers Bank Bldg., Pittsburgh, Pa.
Nagin, Harold (B), Reliance Steel Products Co., McKeesport, Pa.

PUGET SOUND

Marsh, Claude (D), P.O. Box 305, Bremerton, Wash.

GIVE US MORE TANKS!

That is where welding came into its own—for precious hours on the assembly line then could be saved—to produce more tanks with the same number of men on the same line.

And that is where the new welding electrode developed exclusively by PAGE for welding armor plate went to work—after it had met successfully all ballistic tests on plates submitted to the Army Ordnance Department by the tank manufacturers.

Chalk that up as another important contribution by PAGE that will be at the service of industry when Victory brings peace.

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ROCHESTER

King, Harold J. (B), University of Rochester, Dept. of Engrg., Rochester, N. Y.

ST. LOUIS

Evans, W. Stuart (C), 7215 Pasadena Blvd., Normandy, Mo.

SAN FRANCISCO

Groves, Fletcher H. (C), 353 Euclid St., San Bruno, Calif.
Johnston, S. H. (B), Fraser & Johnston Co., 725 Potrero Ave., San Francisco, Calif.
Nelson, Robert V. (D), 531 Visitation Ave., Brisbane, Calif.

SOUTH TEXAS

Witcher, D. V. (C), Dye Welding Supply Co., 1109 Austin St., Houston, Tex.

WASHINGTON, D. C.

Weinman, Earl E. (C), Bonetard & Weinman, 1358 Florida Ave., N. E., Washington, D. C

WESTERN NEW YORK

Conley, Walter (D), 414 Wabash Ave., Kenmore, N. Y.
Doneburg, Ellis H. (D), Bell Aircraft Corp., Elmwood Ave., Buffalo, N. Y.
Kingsley, Cecil (D), % Commonwealth Elec. Corp., Welland, Ont., Can.
Kowalski, Harry V. (D), 1194 Bailey Ave., Buffalo, N. Y.
McCloskey, Richard H. (D), 209 Fremaine Ave., Kenmore, N. Y.
Mellenger, E. R. (B), 520 Virginia St., Buffalo, N. Y.
Mitchell, William H. (C), 536—12th St., Niagara Falls, N. Y.
Prevost, Lawrence (C), 2968 Porter Rd., Niagara Falls, N. Y.

YORK

Bendot, J. M. (B), 826 Rockwood Ave., Mt. Lebanon, 16, Pa.

NOT IN SECTIONS

Bell, Perley C. (D), R.F.D.—Box 37, Bartonsville, Vt.
Boggs, Jay S. (D), 20-B Calhoun Homes, No. Charleston, S. C.
Ford, Isaac L. (D), 1800 E. Strong St., Pensacola, Fla.
Herman, Justin (C), 1633 Linden St., Phoenix, Ariz.
Holmes, Verne E. (C), 312 Diamond Ave., S. E., Grand Rapids, Mich.
Kelly, J. H. (D), P.O. Box 5032, State College Sta., Raleigh, N. C.
Kephart, H. K. (D), 2222 Wagner Ave., Erie Pa.
Maxwell, W. Don (B), P.O. Box 3989, Odessa, Tex.
Messick, Stanley W. (B), Southern Welding School, 1206 Reynolda Rd., Winston-Salem, N. C.
Metz, Virgil P. (D), 2274 Torrey Hill, Toledo, Ohio.
Murray, Jackson L. (D), 1006 Manteo St., Norfolk, Va.
Pierson, Jess A. (B), 427 Mulbury St., Baraboo, Wisc.
Tweed, R. (B), P.O. Box 427, Calcutta India.

SECTION ACTIVITIES

CHICAGO

The May 15th meeting of the Chicago Section was the last of the current successful season. Mr. R. W. Sternke, Superintendent and Production Manager of the Lakeside Bridge and Steel Co., Milwaukee, Wis., gave a very inspiring talk. His subject was "Certified Weldments," which was illustrated by lantern slides and motion pictures, the latter being both black and white and colored types. Mr. Sternke described the exacting procedures employed in the welding of large gear boxes, machinery bases, cranes, gears and other important structural items. The meeting was well attended and an interesting discussion followed the speakers' presentation.

At the start of the meeting the new officers and directors were introduced to the membership. This was followed by Mr. L. S. McPhee, Middle Western Division Vice-President, presenting Mr. A. M. Unger, the retiring chairman, with the A.W.S. past-chairman's pin.

A farewell dinner was given on Wednesday evening, May 13th, at the Lake Shore Club in honor of Mr. Gene Balsley, Welding Engineer, for the Link Belt Co. Mr. Balsley who has been active in the Chicago Section, severed his present connection to accept a new position in the east.

The officers for the forthcoming year are as follows: E. R. Seabloom, Crane Co., *Chairman;* R. L. Kohlbry, Machinery & Welder Corp., *Vice-Chairman;* T. B. Jefferson, Editor of *Welding Engineer*, *Secretary-Treasurer*. Directors: Tom Harle, J. H. Hruska, C. D. Young, L. C. Monroe, H. M. Downing, C. L. Pfeiffer, E. P. Everhard, C. G. Bassler, E. J. DeWitt, R. S. Kenrick, M. H. Wigton, J. C. Menzies, C. J. McGregor.

CLEVELAND

Chairmen of Operating and Advisory Committees of the Cleveland Section for 1942–43 are announced by R. J. Kriz, chief inspector, James H. Herron Co., chairman of the section.

Operating Committees and their chairmen include: Programs and Papers, J. Wagner, Burdett Oxygen Co.; Publicity, Ed C. Powers, James F. Lincoln Arc Welding Foundation; Reception and Dinner, R. Yarrow, Republic Structural Iron Works; Properties, Cal Wyss, Reliance Electric & Engineering Co.; Membership, T. G. Kells, Anthony Carlin Co.; Code, J. F. Maine, Republic Structural Iron Works; Nominations and Constitution & By-Laws, E. T. Scott, Cleveland School of Welding; Symposium, J. Morrill, Lincoln Electric Co.; Inter-Societies—Publ., C. T. Elder, Cleveland Electric Illuminating Co.

Advisory Committees and their chairmen include: Sponsors, J. Wolfenden, Hobart Brothers Co.; Resistance Welders, J. E. Mallet, Taylor-Winfield Corp.; Arc Welders, J. F. Vickery, General Electric Co.; Gas Welders, E. B. Pederson, Air Reduction Sales Co.; Fabricators, L. Burr, The Austin Co.; Engineers, R. E. Kinkead, Consulting Welding Engineer; Metallurgy, J. C. Hodge, Wellman Engineering Co.; Marine, L. C. Host, American Bureau of Shipping; Inter-Societies, A. F. Davis, The Lincoln Electric Co.; Railway, W. E. Davis, The Cleveland Railway Co.

LOS ANGELES

The Los Angeles Section has their last meeting of the season on June 18th. The following officers were inducted for the year 1942–43:

Chairman, Francis H. Stevenson, Asst. Supt., Vega Airplane Co.; *Vice-Chairman*, Alex Maradudin, Research Engr., Standard Oil Co.; *Secretary-Treasurer*, E. O. Williams, L. A. Branch Mgr., Victor Equipment Co.

Executive Committee: A. K. Brumbaugh, Inspection Dept., General Petroleum Corp.; Chas. Babbitt, Welding Engr., Western Pipe & Steel Co.; C. W. Johnson, Supvr., California Shipbuilding Corp.; M. J. Karn, Owner, Welding Equipment Rental Service; Roy Tadd, Mgr. Welding Division, Ducommun Corp.; Walter Thomas, Welding Engr., Western Pipe & Steel Co.; Jim Gowing, Representative, Hobart Bros. Co.

At the last meeting a very interesting subject was covered by Mr. Thomas E. Piper of Northrop Aircraft, Inc. Mr. Piper, with the assistance of others in the Research Department, has developed "Heliarc," a new process of welding.

NORTHERN NEW YORK

The following officers and directors of the Northern New York Section were elected to serve the Section during the coming year:

Chairman, M. F. Sayre, Civil Eng. Dept., Union College; *1st Vice-Chairman*, E. R. Spittler, General Electric Co.; *2nd Vice-Chairman*, H. S. Swan, American Locomotive Co.; *Secretary-Treasurer*, R. S. Pelton, General Electric Co.

ATTACK

PRODUCTION PROBLEMS

with

RESISTANCE WELDING

In recent months, Resistance Welding has proved to be much more than a good way to assemble metal products. It is helping to make more and better war materials by producing parts at high speed and low cost that formerly required slow and expensive casting or machining operation. It is providing a variety of ways to eliminate bolts, rivets and other fastening devices; to produce smooth, unbroken surfaces that require less preparation for finishing; to cut down weight; to increase strength; to simplify the construction of many products.

In addition, Resistance Welding is helping to keep other equipment on the job by solving repair and maintenance problems and in the conservation and re-use of hard-to-get materials.

An experienced welding engineer, representing one of the member companies listed here, can tell you quickly just what Resistance Welding can do for you. Why not call one in today?

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MANUFACTURER'S ASSOCIATION
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Federal Machine and Welder Company, Warren, Ohio
Multi-Hydromatic Welding and Manufacturing Co., Detroit, Mich.
National Electric Welding Machines Co., Bay City, Mich.
Progressive Welder Company, Detroit, Mich.
Swift Electric Welder Company, Detroit, Mich.
Taylor-Hall Welding Corporation, Worcester, Mass.
Taylor-Winfield Corporation, Warren, Ohio
Thomson-Gibb Electric Welding Co., Lynn, Mass
Welding Machines Mfg. Company, Detroit, Mich.

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S-M-S Corporation, Detroit, Mich.
Electroloy, Inc., New York, N. Y.
Welding Sales and Engineering Co., Detroit, Mich.
P. R. Mallory and Co., Indianapolis, Ind.

Executive Committee: C. I. MacGuffie, General Electric Co.; E. F. Potter, General Electric Co.; R. A. Gilbert, General Electric Co.; A. F. Stiglmeier, N. Y. C. R.R.; R. W. Clark, General Electric Co.; J. R. Lipsky, American Locomotive Co.

Committee Chairmen: Public Relations, C. I. MacGuffie; Membership, J. R. Lipsky; Meetings and Papers, J. E. Waugh; Education, H. S. Swan; Coordinating, R. S. Pelton; Nominating, E. F. Potter.

SAN FRANCISCO

The following are the newly elected officers for the San Francisco Section:

Chairman, F. A. Longo, Southern Pacific Co.; *Vice-Chairman,* M. Maltseff, Western Pipe & Steel Co.; *Secretary,* R. E. Labagh, Victor Equipment Co.; *Treasurer,* H. W. Saunders, Air Reduction Sales Co.

The May meeting was held at the Athens Club, Oakland, on May 22nd. Approximately 80 members and guests were present. Prof. E. R. Mertz of Leland Stanford Jr. University presented a very interesting and timely subject on "Welding of Low Alloy, High Tensile Steels." An open discussion was then held followed by a technicolor sound motion picture, entitled "Unfinished Rainbows."

A double feature program was arranged for the June meeting held on the 26th at the Athens Club. A Round Table discussion of the welding of manganese steel in which everyone present was invited to take part, was the first feature. Following this, through the courtesy of Republic Steel Company, a motion picture entitled "Enduro—Republic's Perfected Stainless Steel" was shown.

Employment Service Bulletin

SERVICES AVAILABLE

A-440. Graduate Engineer. B.S. degree. 11 years' experience in both gas and electric welding. Have instructed both types of welding and am now supervising National Defense Training at a Trade School. Age 28. Married.

A-441. Position wanted by welder with three years' construction welding, electric and acetylene, both here and abroad. Will accept foreign employment. Can furnish recommendations.

A-442. Welding Engineer; 10 years as Welding Engineer. Experience on production of welded pressure vessels, gun carriages, Diesel engine frames, USN condensers. Materials of mild, low alloy, stainless and chrome steels. X-ray work. Knows Welding Codes, Army and Navy Specifications. Experienced in Union Melt, General Electric, Lincoln automatic operation. Grad. M.E. Knows Physical Metallurgy. Now employed. Can get release. Not subject to Draft. Member A.W.S. Desires permanent position in manufacturing or consulting field.

SOME HIGHLIGHTS OF THE ANNUAL MEETING PROGRAM, AMERICAN WELDING SOCIETY — HOTEL CLEVELAND, CLEVELAND, OCTOBER 12-16

Prizes—Medals

Come and see who will be awarded the Samuel Wylie Miller Memorial Medal for outstanding achievements during the past year—the Lincoln Gold Medal for the paper judged the greatest contribution to the advancement and use of welding—who will be the prize winners for the best Resistance Welding papers.

Technical Sessions

Altogether there will be some 57 papers presented, covering every phase of welding, by outstanding leaders in the welding industry. The entire meeting has been centered around the direct objective of *winning the war.*

Training of Welding Operators and Qualifications:

Two papers will be presented dealing with the training of welding foremen and methods of construction for welding operators developed by the U. S. Office of Education.

Fatigue and Impact:

How do welds behave under dynamic stresses? What happens to metals when they are subjected to combined stresses? What is the relative fatigue strength of welded joints and the base metal? What is the impact strength of high-alloy steels? The answers will be furnished in this particular session.

War Production:

Two separate sessions will be devoted to this important subject. Special papers will deal with applications of flame hardening. The developments in A.C. welding for high-quality vertical and overhead welds, the conservation and effective use of equipment and supplies for cutting and welding, new developments in aluminum and bronze welding, automatic arc welding for production work, welded steel tubing and its application in war production, and several others.

Weldability of Steel:

Here again two sessions will be devoted to this most important subject. For the first time, papers will be presented which will approach the weldability problem in a fundamental way. Specific papers will deal with the effect of cooling rates on the base material and on the welded joints, the development of special weldability tests will be indicated, the effect of carbon and manganese on the weldability of steels will be covered in an especially comprehensive report representing the result of many thousands of dollars of research work. Correlation of the various weldability tests with service experience will be indicated by several authors.

Aircraft Welding:

Probably no other subject is more important at the present time in the application to welding and speeding up of the welding production. The movement has gained so much headway that three separate sessions will be devoted to aircraft welding. Papers will cover airplane propeller blades, the welding of special alloy steels used in aircraft tubing, the application of resistance welding in its various forms to aluminum and magnesium alloys, recommended standards for spot welding in the aircraft industry, the development of special electrodes, surveys of present practices and several other phases.

Gas Cutting:

Hand in hand with welding in its applications in speeding up production is gas cutting. Several papers will indicate the development of cutting in steel mills, improved methods of machine flame cutting, and factors affecting the accuracy of machine cutting.

Fundamentals of Resistance Welding:

Two separate sessions will be devoted to this important phase of the work. Developments are so thick and fast in this industry that it is necessary to attend these sessions to keep abreast of such developments as refrigerant-cooled spot-welding electrodes, spot welding of hardenable steels, some unusual resistance-welding developments, spot welding of special high-alloy steels, high tensile steels, design data, preparation of aluminum alloys for welding, etc.

Welding of Ordnance:

Many important phases of the application of welding in ordnance work such as the development of filler metals for critical materials, the welding of heavy plate of hardenable alloys, the welding of gun carriages, will be covered.

Shipbuilding:

Probably the greatest amount of welding is in connection with our shipbuilding program. Here is an opportunity to learn first hand what is going on in this important industry. Find out how they tackle their problems of increasing production, how they solve their distortion and shrinkage problems, how welding is applied in submarine construction.

Other Features

It is impossible in this small space to describe in detail other special features such as a series of educational motion pictures on all phases of welding, research sessions, committee meetings, Section-Officers Conference, Business Meetings and the like.

Last but not least, the opportunity of meeting your fellow workers and discussing with them privately your problems is worth several times the time and effort of attending these sessions. These conferences materially aid in speeding up the war production effort.

Several Societies will hold meetings at the same time in order to save time and money of people interested in the same field of endeavor. The meetings are held in conjunction with the National Metal Exposition.

REMEMBER THE DATE

Cleveland

October 12–16, 1942